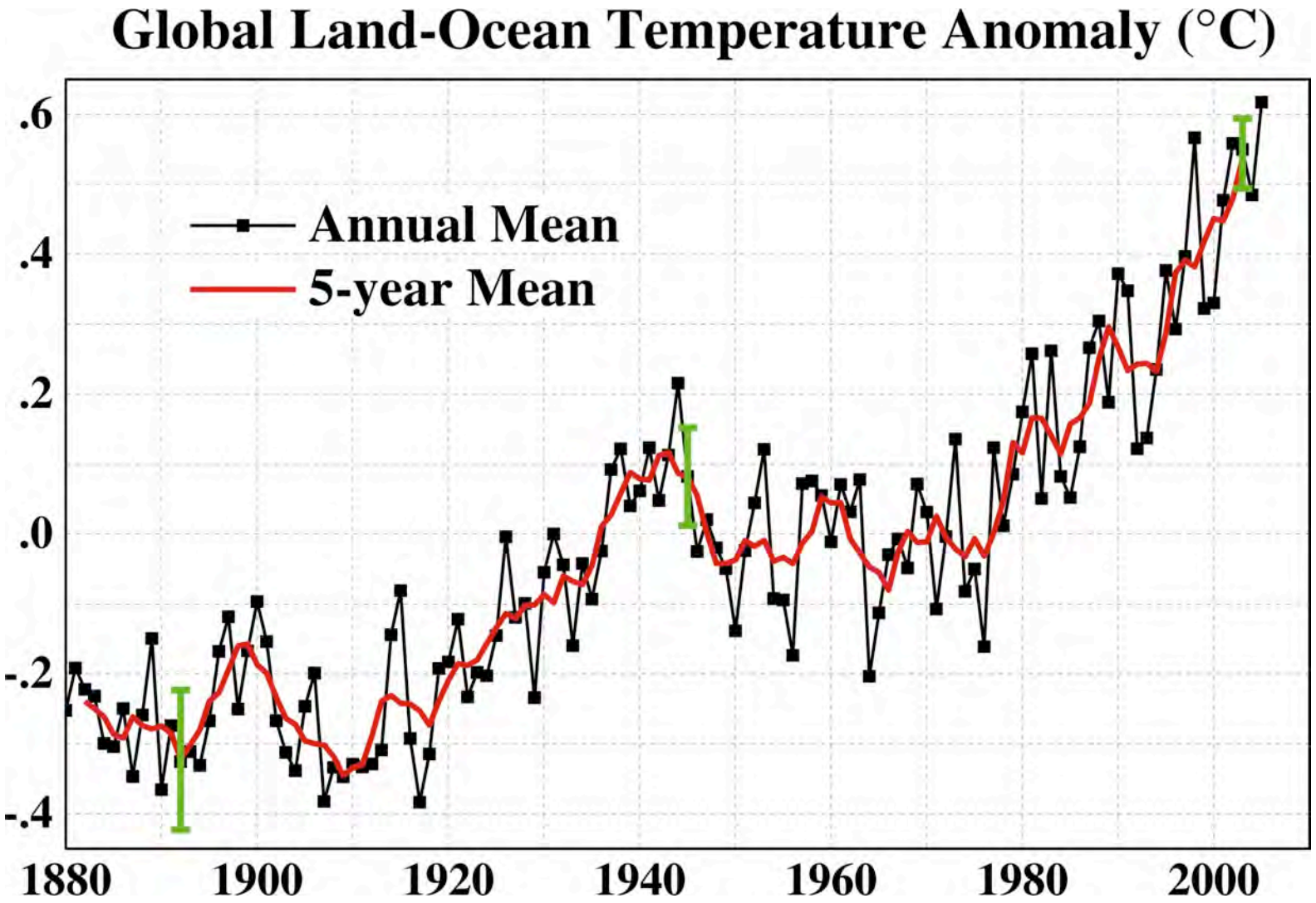
Global Climate Change
Is There Still Time to Avoid Disastrous Effects?

Jim Hansen

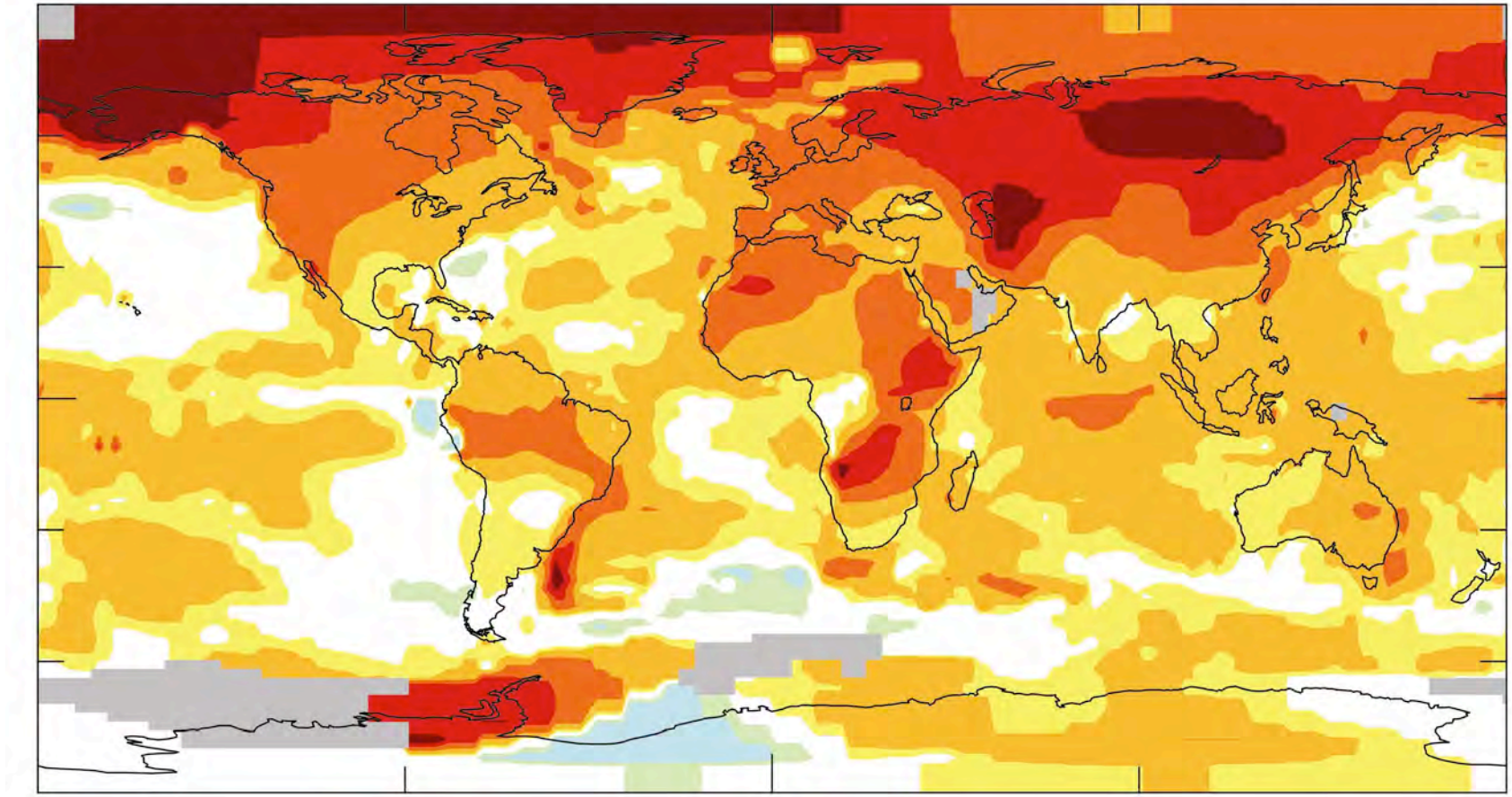
13 September 2006

Climate Change Research Conference
Sacramento, California

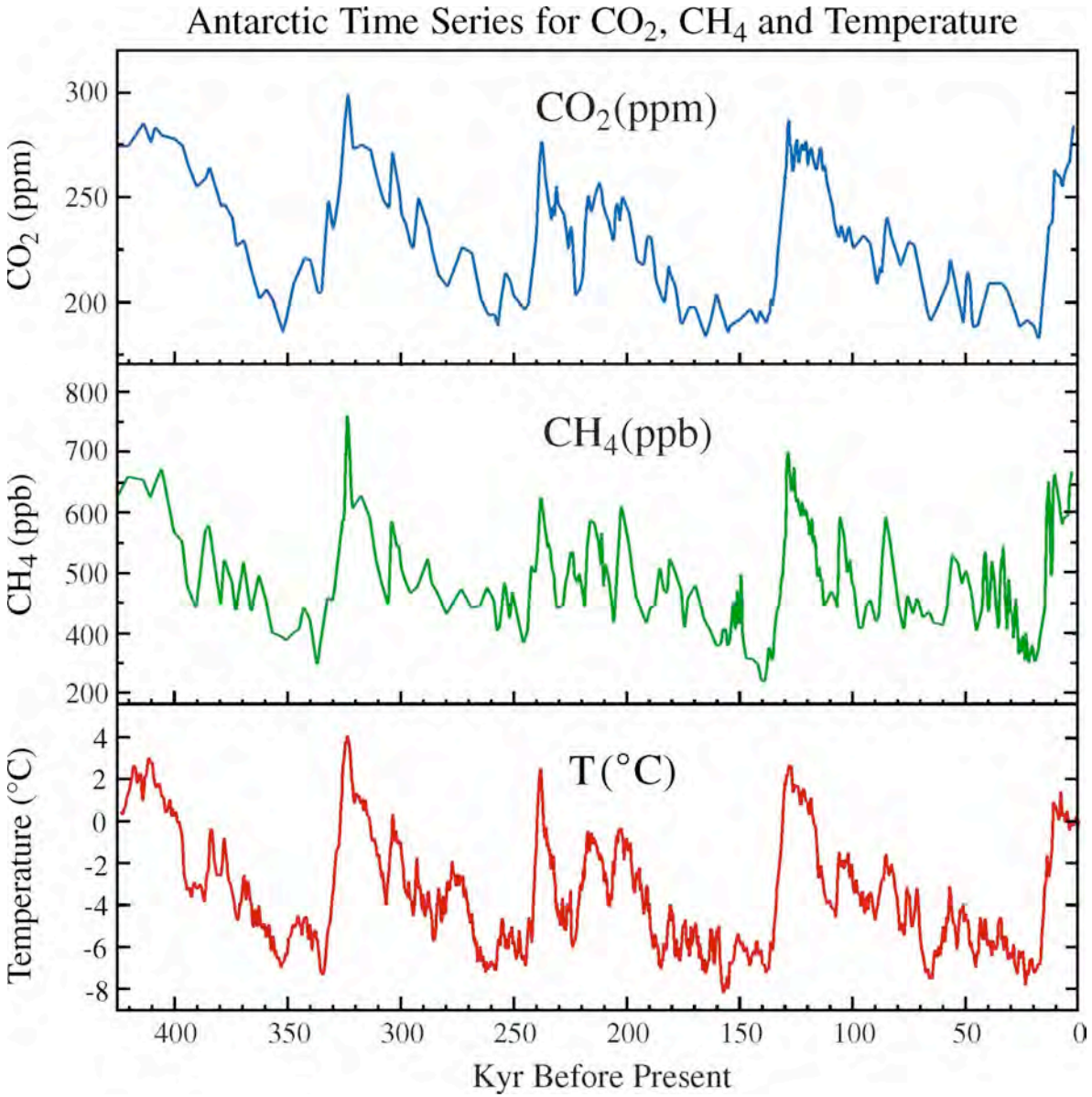

Global Land-Ocean Temperature Anomaly (°C)
.6
.4
.2
.0
-.2
-.4
Annual Mean
5-year Mean
1880
1900
1920
1940
1960
1980
2000

2001-2005 Mean Surface Temperature Anomaly (°C)

Base Period = 1951-1980 Global Mean = 0.53



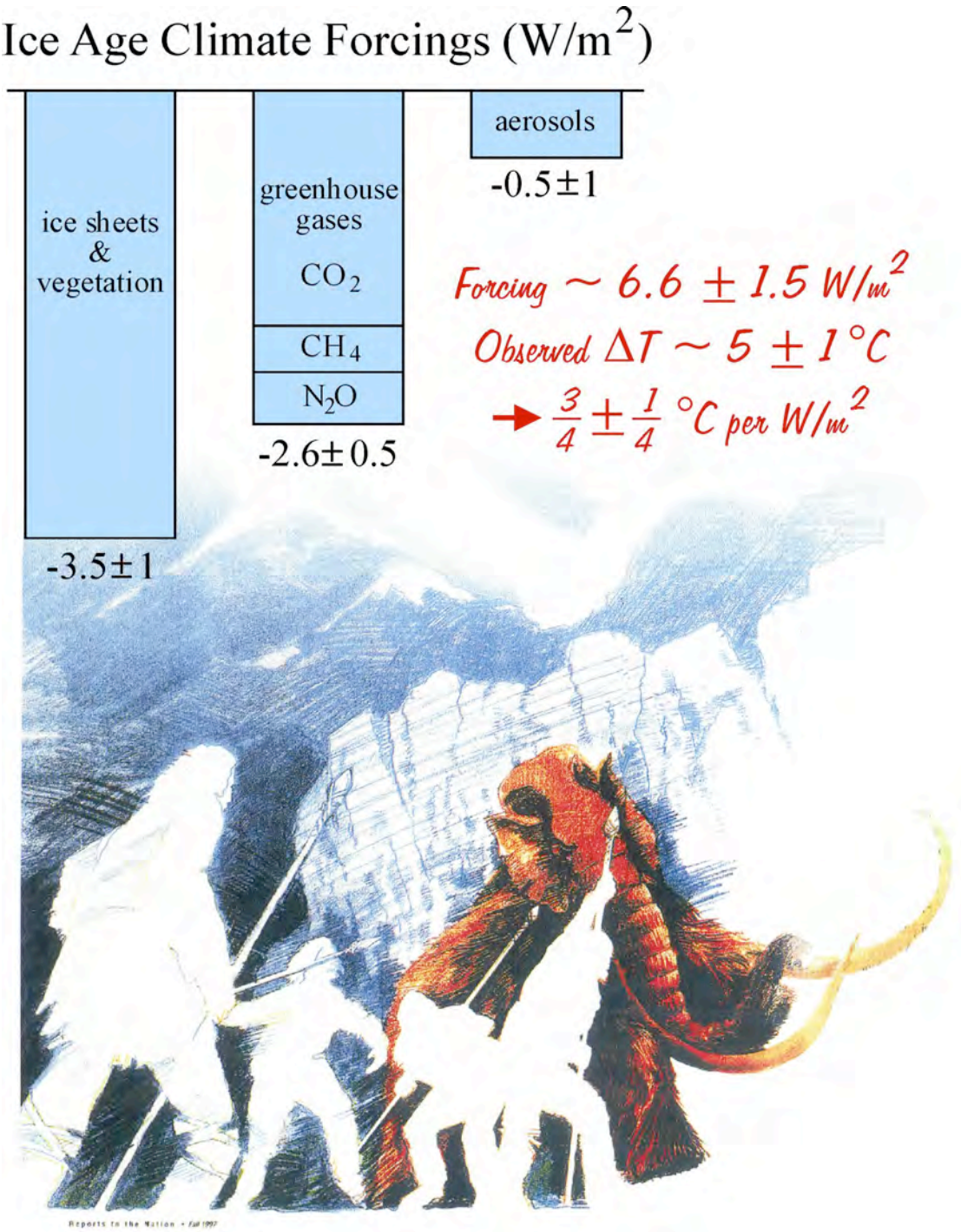
-2 -1.6 -1.2 -.8 -.4 -.2 .2 .4 .8 1.2 1.6 2.1



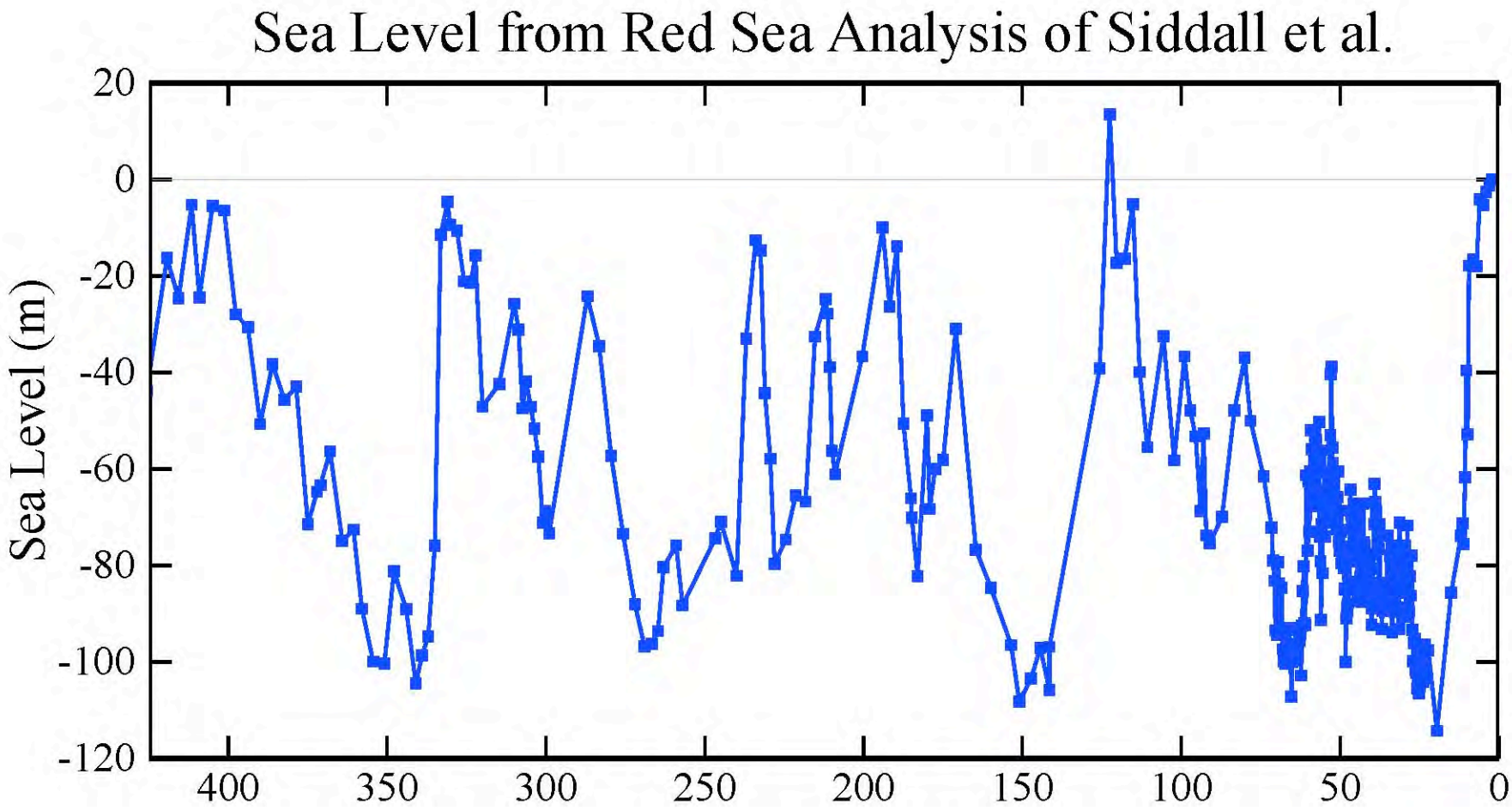
CO_2, CH_4 and temperature records from Antarctic ice core data

Source: Vimeux, F., K.M. Cuffey, and Jouzel, J., 2002, "New insights into Southern Hemisphere temperature changes from Vostok ice cores using deuterium excess correction", *Earth and Planetary Science Letters*, **203**, 829-843.

Ice Age Forcings Imply Global Climate Sensitivity ~ ¾°C per W/m^2.

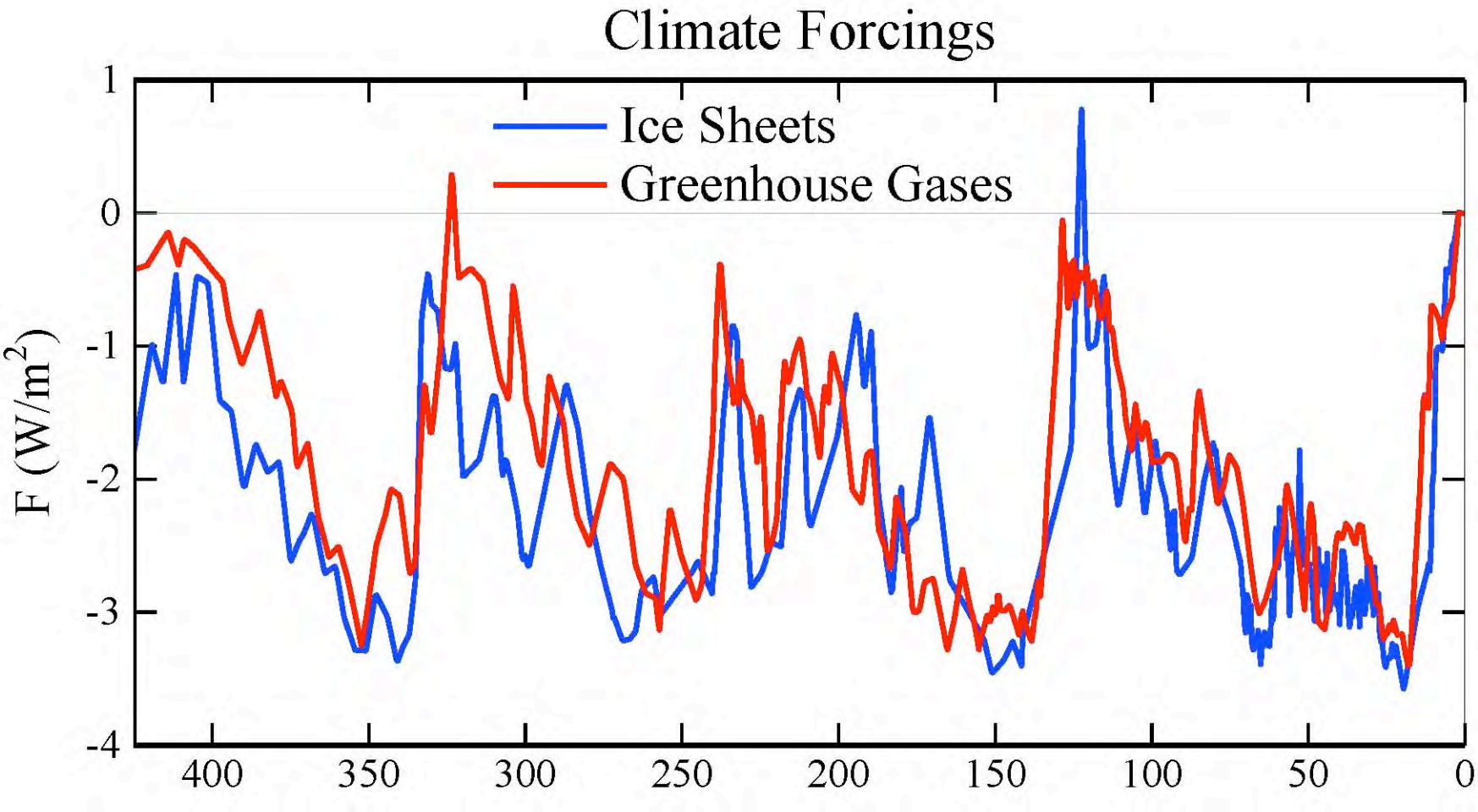


Source: Hansen et al., *Natl. Geogr. Res. & Explor.,* **9**, 141, 1993.



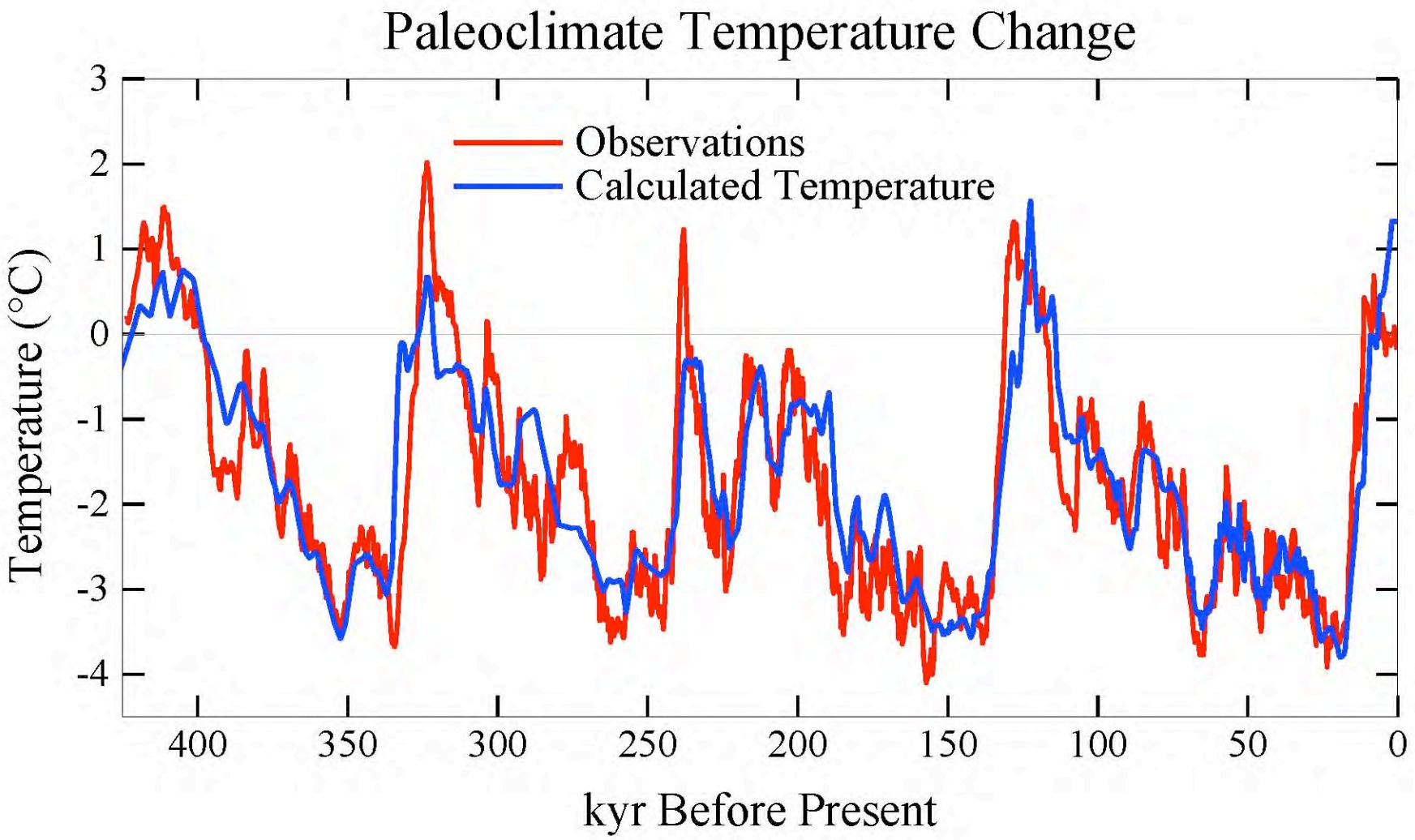
Global sea level extracted, via a hydraulic model, from an oxygen isotope record for the Red Sea over the past 470 kyr (concatenates Siddall's MD921017, Byrd, & Glacial Recovery data sets; AMS radiocarbon dating).

Source: Siddall et al., *Nature*, **423**, 853-858, 2003.



Ice sheet forcing ≅ (sea level)$^{2/3}$

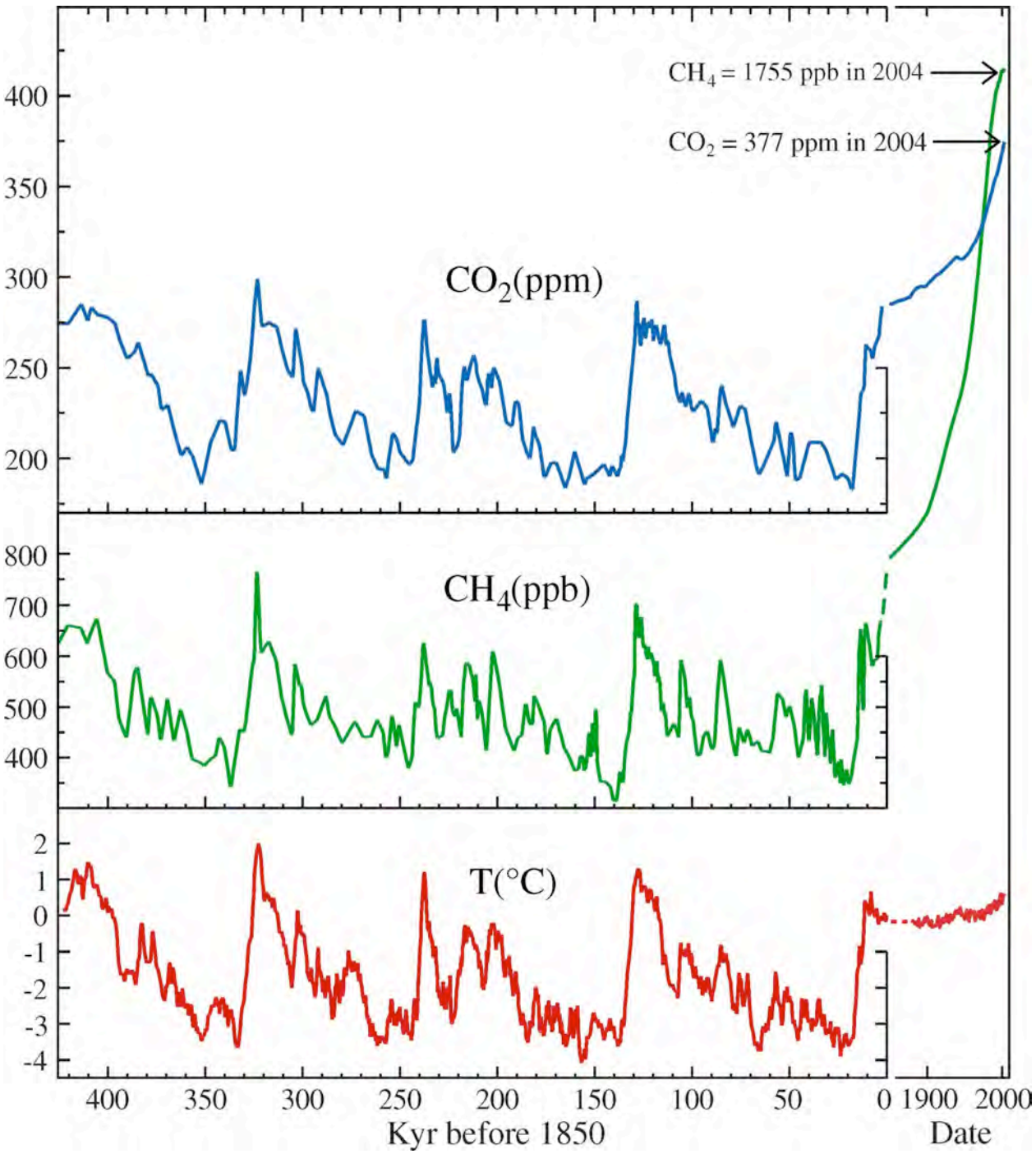
GHGs = CO_2 + CH_4 + N_2O (0.15 forcing of CO_2 + CH_4)



Observations = Vostok ΔT/2.

Calculated temperature = Forcing x 0.75°C /W/m^2

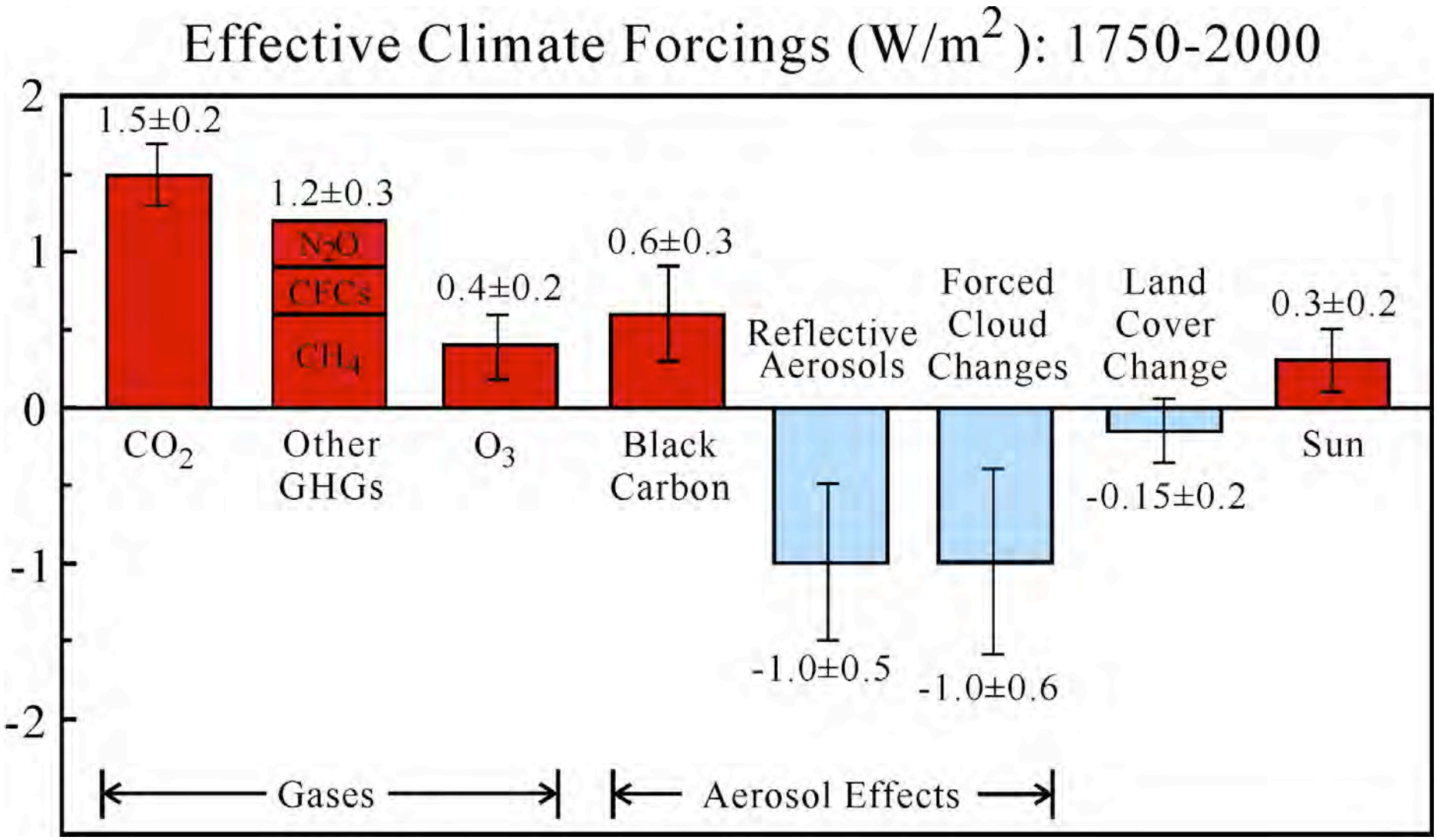
CO_2,CH_4 and estimated global temperature (Antarctic $\Delta T/2$ in ice core era) 0 = 1880-1899 mean.



Source: Hansen, *Clim. Change*, **68**, 269, 2005.

Implications of Paleo Forcings and Response

1. "Feedbacks" (GHGs & ice area) are the chief mechanisms for paleo temperature changes.
2. Instigators of climate change include: orbital variations, any other small forcings, chaos.
3. Climate on long time scales is very sensitive to even small forcings.
4. Another "ice age" cannot occur unless humans become extinct.
5. Humans now control global climate, for better or worse.

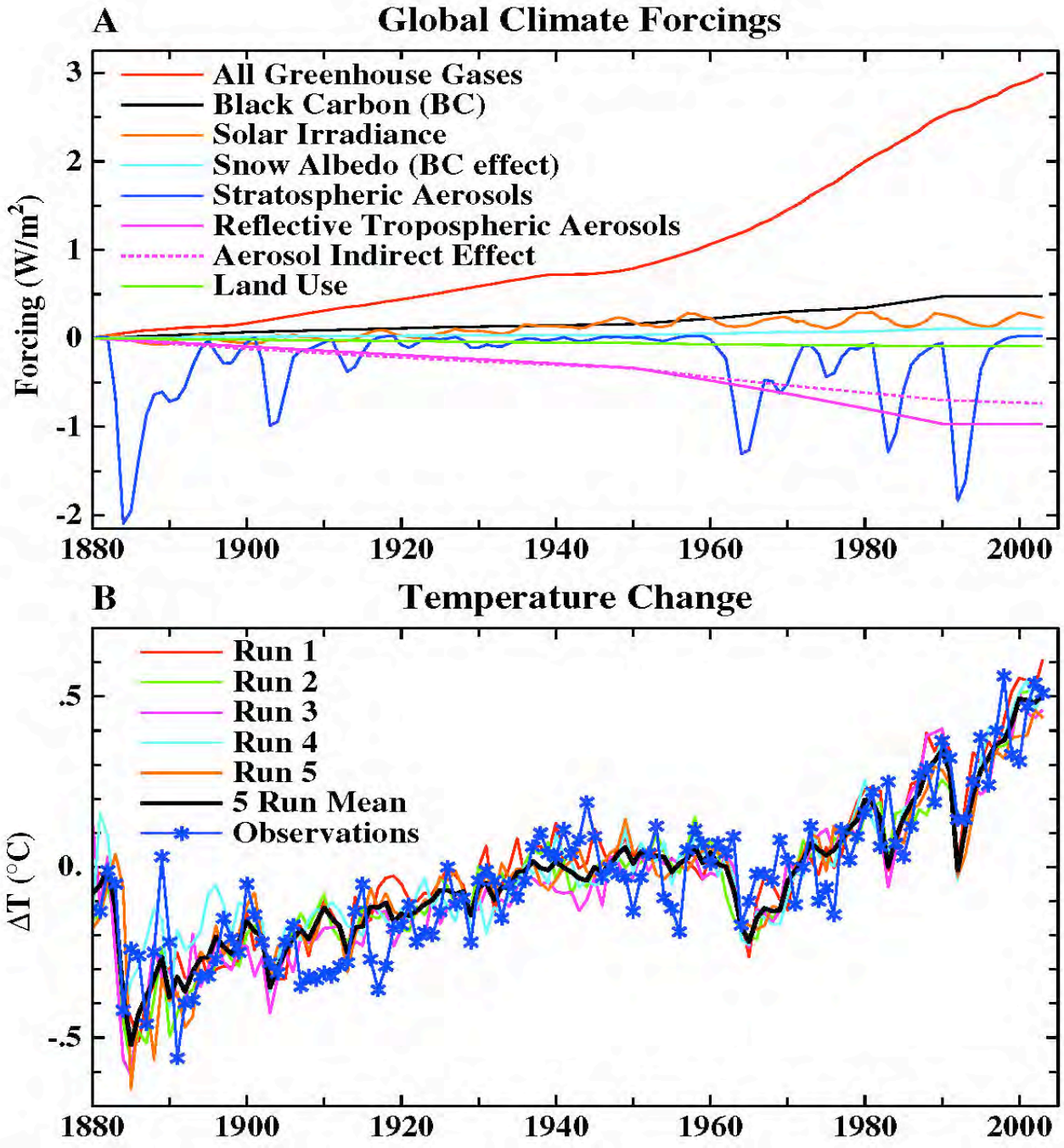


Climate forcing agents in the industrial era. "Effective" forcing accounts for "efficacy" of the forcing mechanism

Source: Hansen et al., JGR, **110**, D18104, 2005.

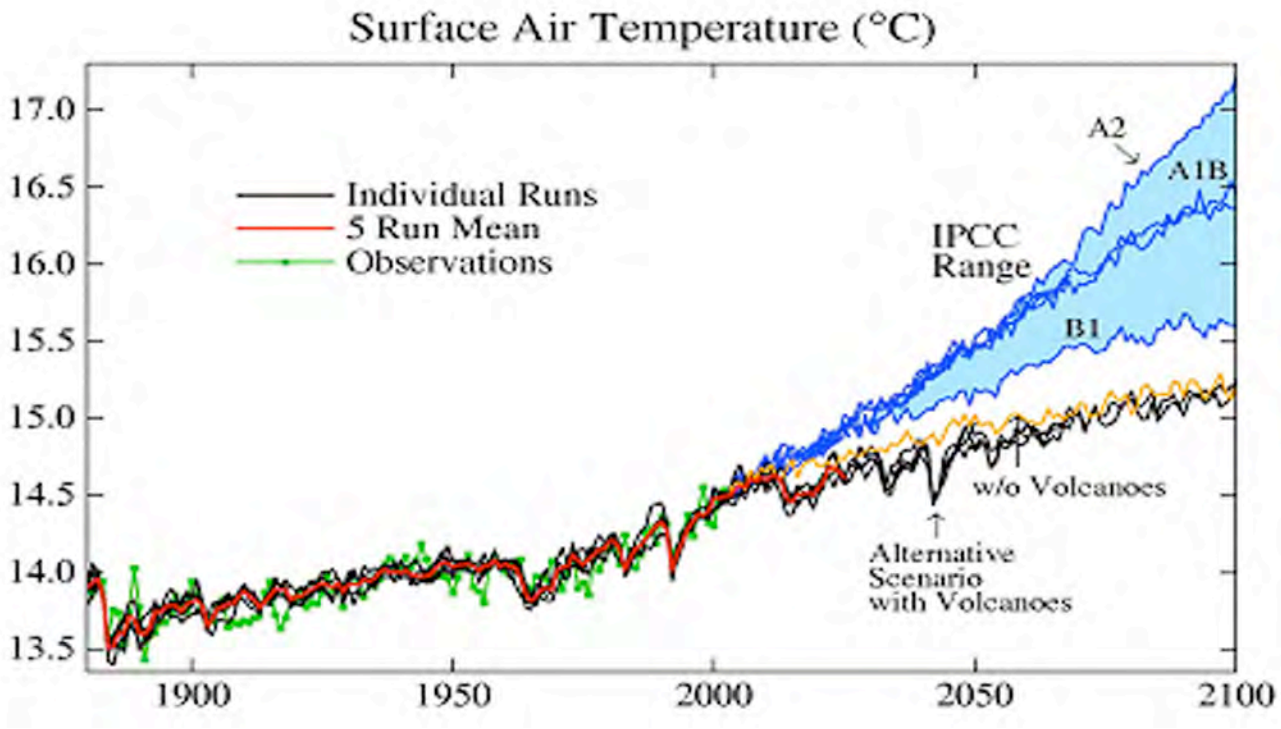
(A) Forcings used to drive climate simulations.

(B) Simulated and observed surface temperature change.



Source: Earth's energy imbalance: Confirmation and implications. *Science* **308**, 1431, 2005.

21st Century Global Warming



Climate Simulations for IPCC 2007 Report

- **Climate Model Sensitivity 2.7-2.9ºC for $2xCO_2$**
  (consistent with paleoclimate data & other models)
- **Simulations Consistent with 1880-2003 Observations**
  (key test = ocean heat storage)
- **Simulated Global Warming < 1ºC in Alternative Scenario**

Conclusion: Warming < 1ºC if additional forcing ~ 1.5 W/m²

Source: Hansen et al., *to be submitted to J. Geophys. Res.*

United Nations
Framework Convention on Climate Change

Aim is to stabilize greenhouse gas emissions…

"…at a level that would prevent dangerous anthropogenic interference with the climate system."

Metrics for "Dangerous" Change

Extermination of Animal & Plant Species

1. Extinction of Polar and Alpine Species
2. Unsustainable Migration Rates

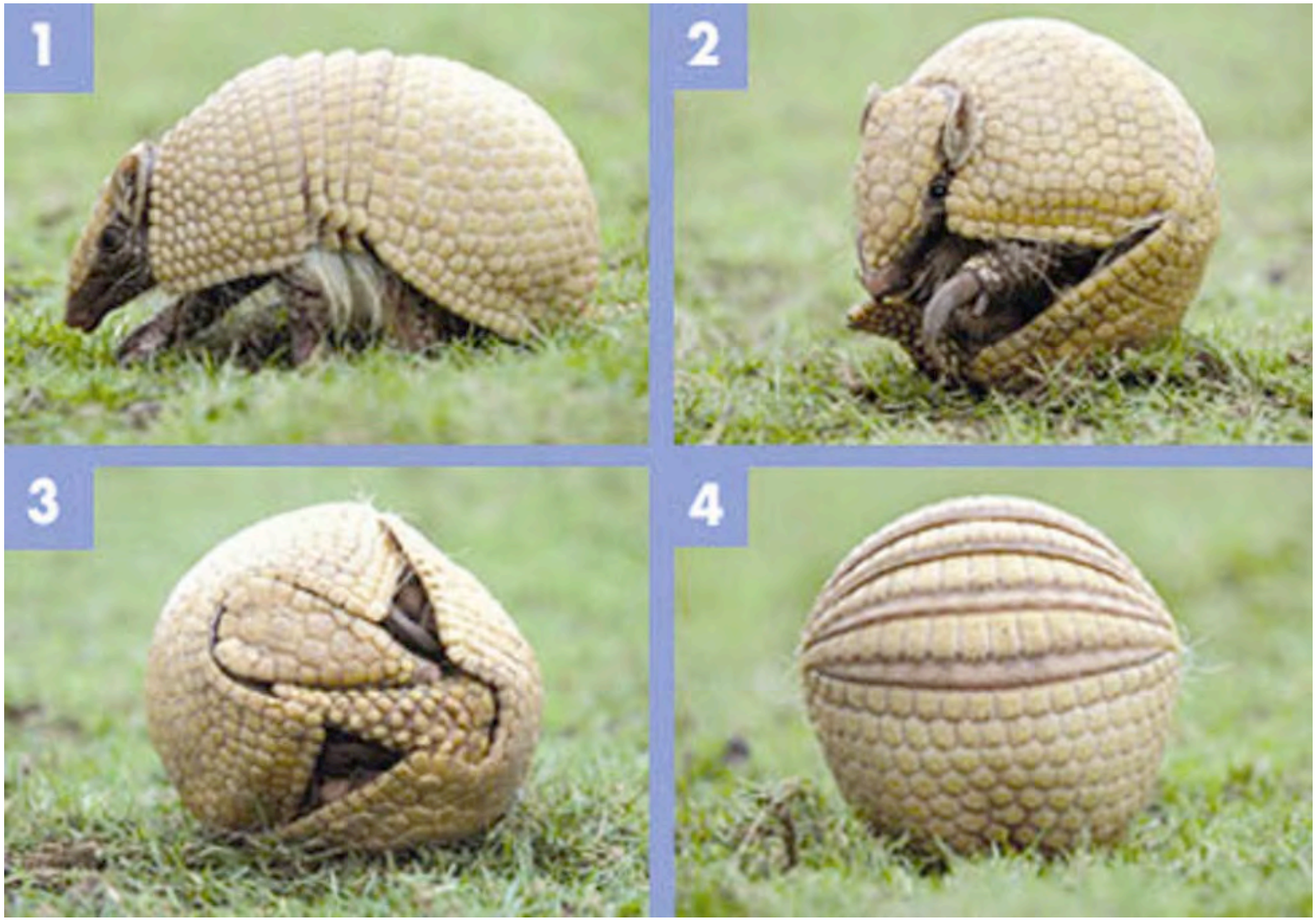
Ice Sheet Disintegration: Global Sea Level

1. Long-Term Change from Paleoclimate Data
2. Ice Sheet Response Time

Regional Climate Change

1. General Statement
2. Arctic, Tropical Storms, Droughts/Floods

Armadillos: One of the Surviving Species?



Arctic Climate Impact Assessment (ACIA)

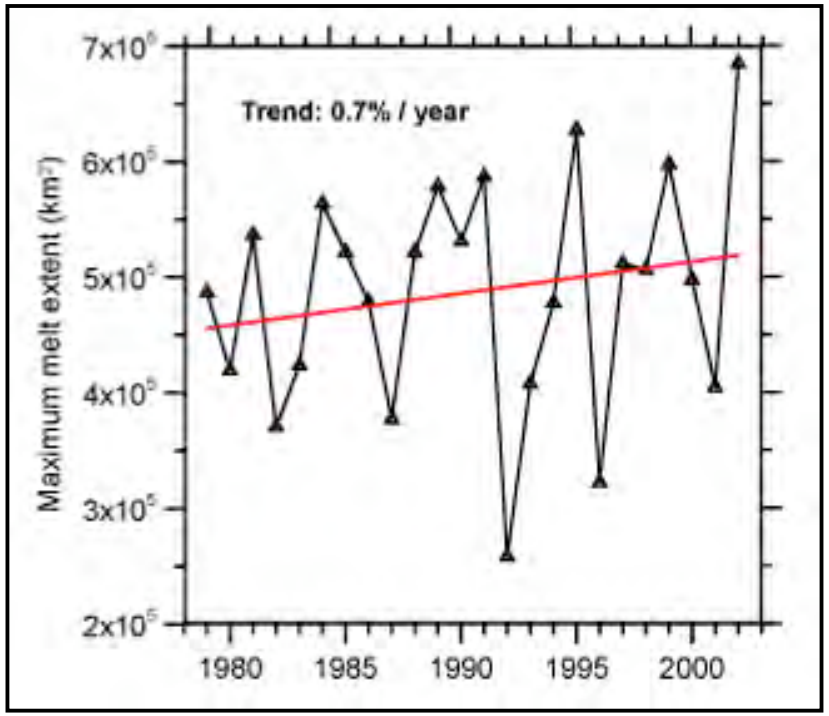
Sources: Claire Parkinson and Robert Taylor

Survival of Species

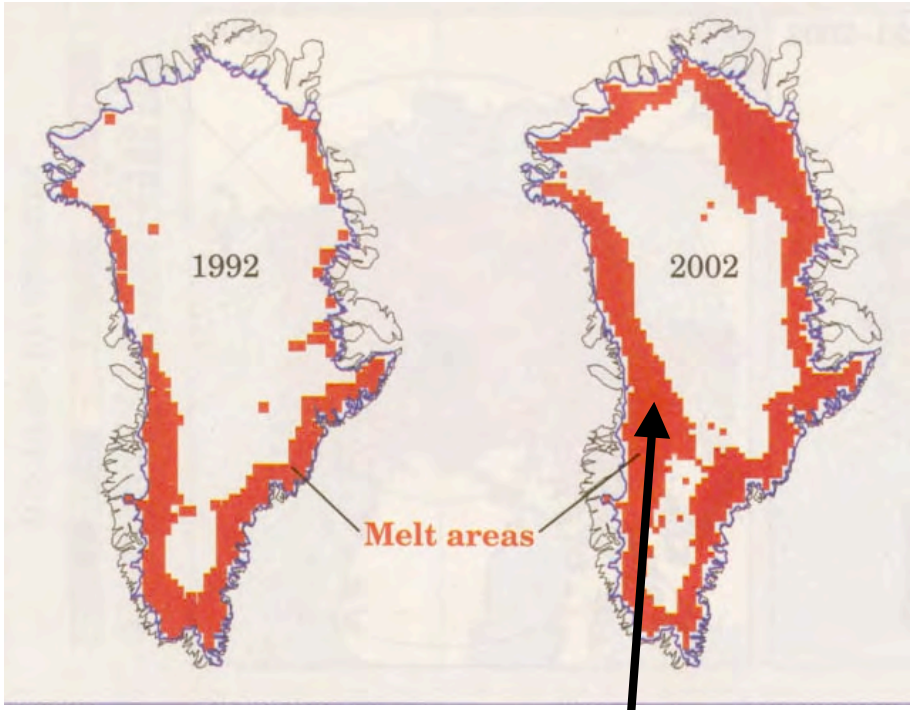
1. "Business-as-Usual" Scenario
   - Global Warming ~ 3ºC
   - Likely Extinctions ~ 50 percent
2. "Alternative" Scenario
   - Global Warming ~ 1ºC
   - Likely Extinctions ~ 10 percent

Climate Feedbacks → Scenario Dichotomy

Increasing Melt Area on Greenland



- 2002 all-time record melt area
- Melting up to elevation of 2000 m
- 16% increase from 1979 to 2002



70 meters thinning in 5 years

Satellite-era record melt of 2002 was exceeded in 2005.

Source: Waleed Abdalati, Goddard Space Flight Center

Surface Melt on Greenland

Melt descending into a moulin, a vertical shaft carrying water to ice sheet base.

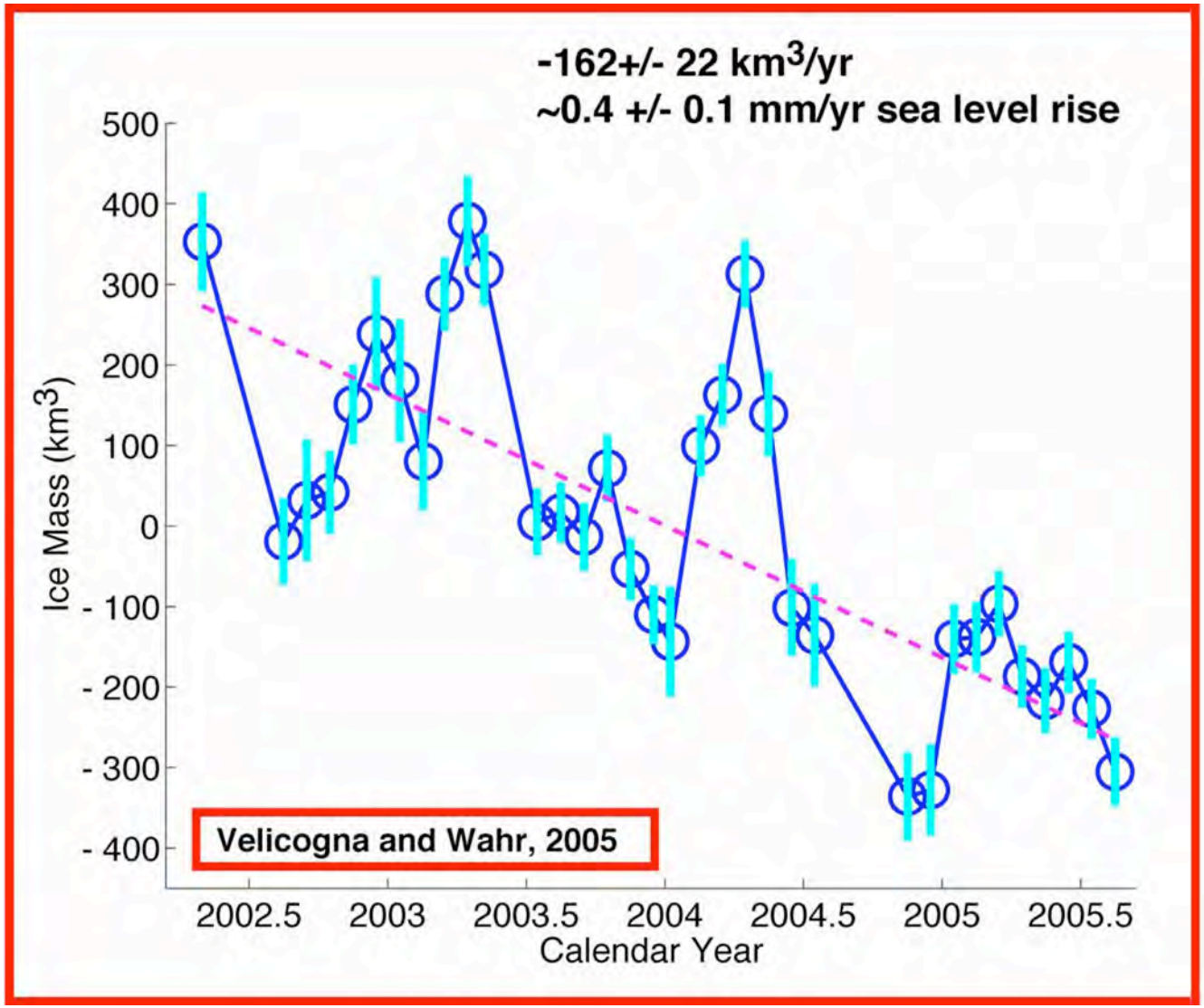
Source: Roger Braithwaite, University of Manchester (UK)

Jakobshavn Ice Stream in Greenland

Discharge from major Greenland ice streams is accelerating markedly.

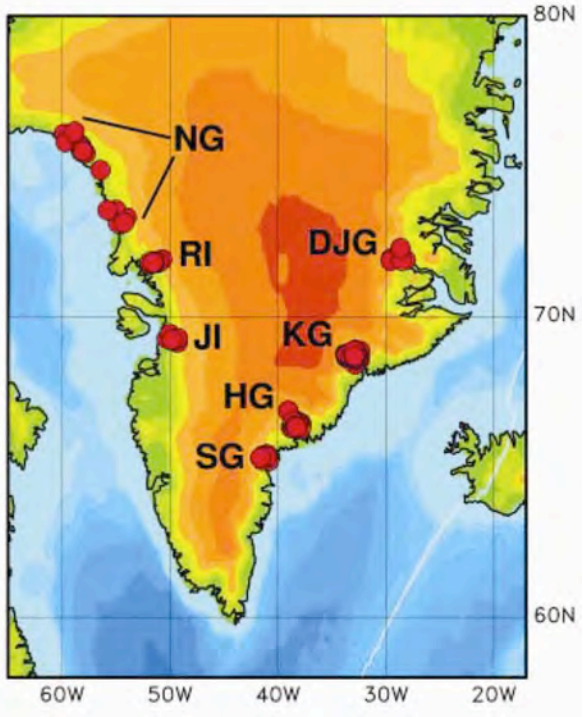
Source: Prof. Konrad Steffen, Univ. of Colorado

Greenland Mass Loss – From Gravity Satellite

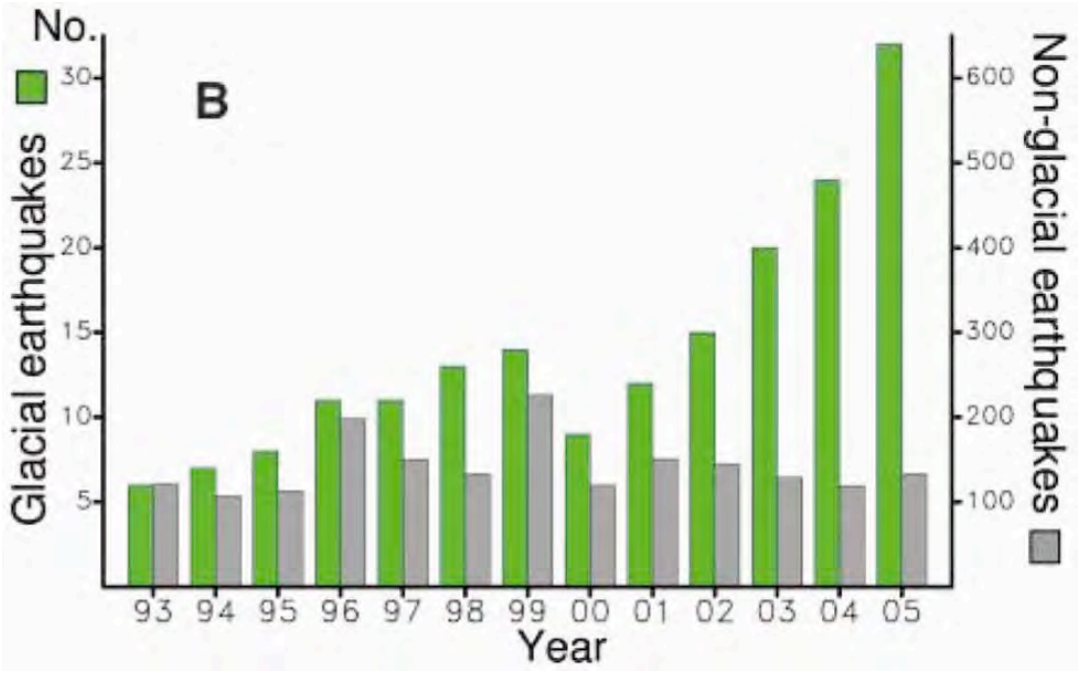


Glacial Earthquakes on Greenland

Earthquake Locations



Annual Number of Quakes*



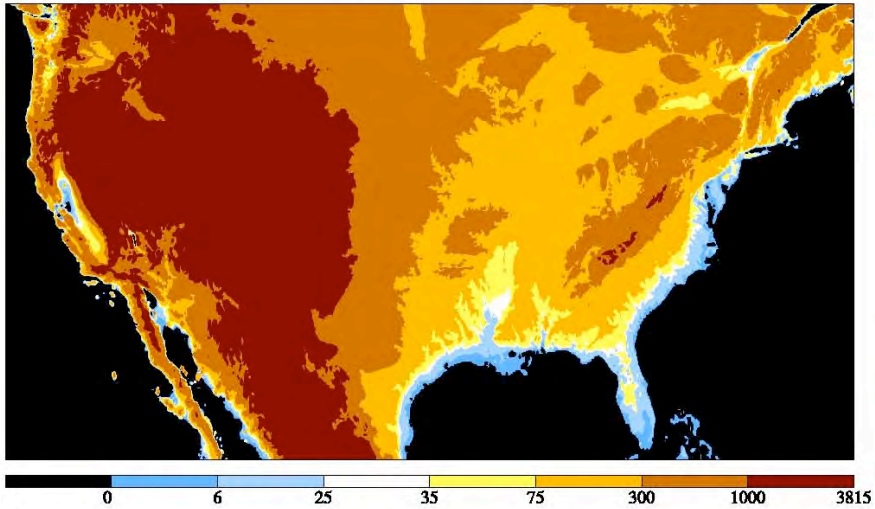
* 2005 bars capture only first 10 months of 2005

Location and frequency of glacial earthquakes on Greenland. Seismic magnitudes are in range 4.6 to 5.1.

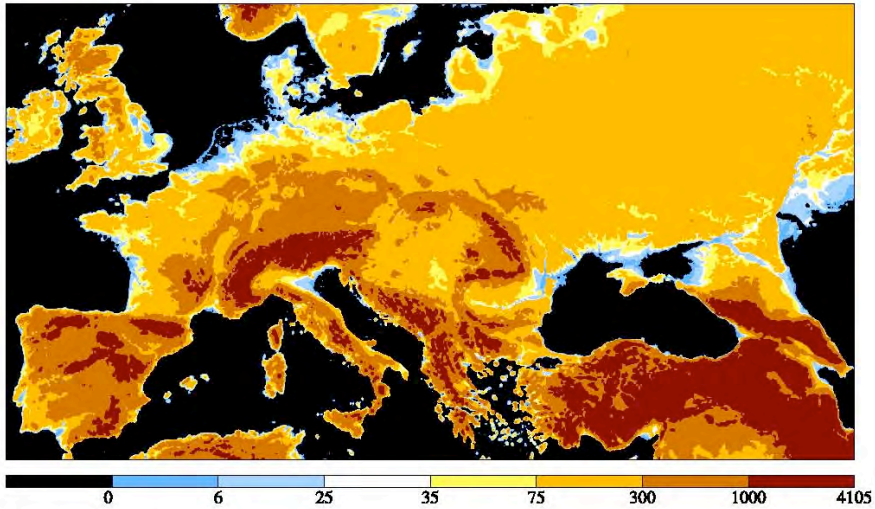
Source: Ekstrom, Nettles and Tsai, *Science*, **311**, 1756, 2006.

Areas Under Water: Four Regions

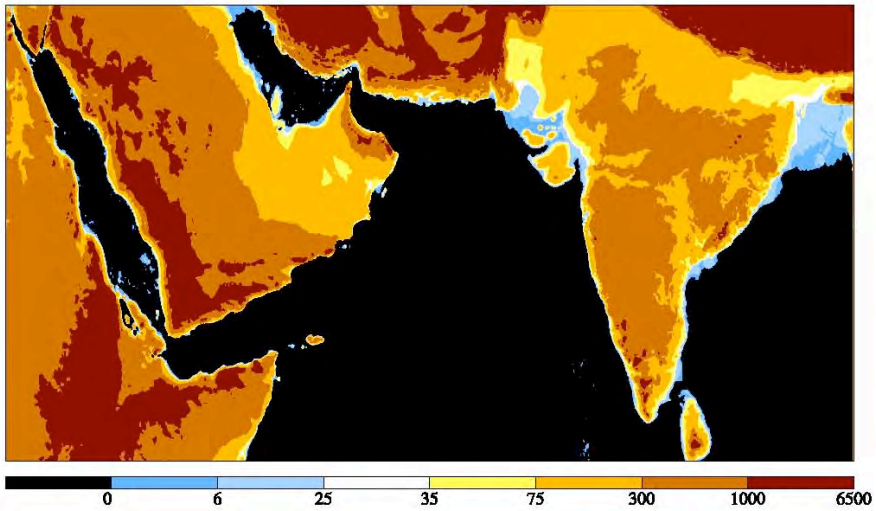
U.S. Area Under Water



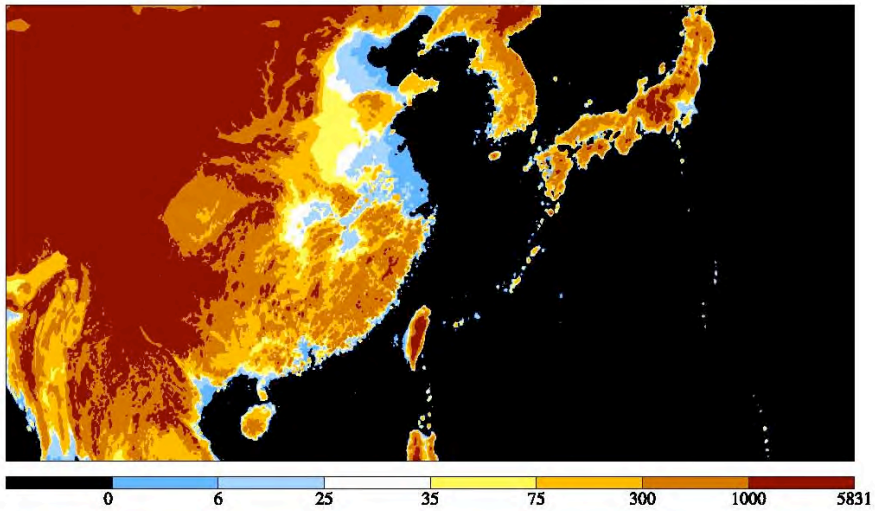
Europe Area Under Water



Central Asia: Area under Water



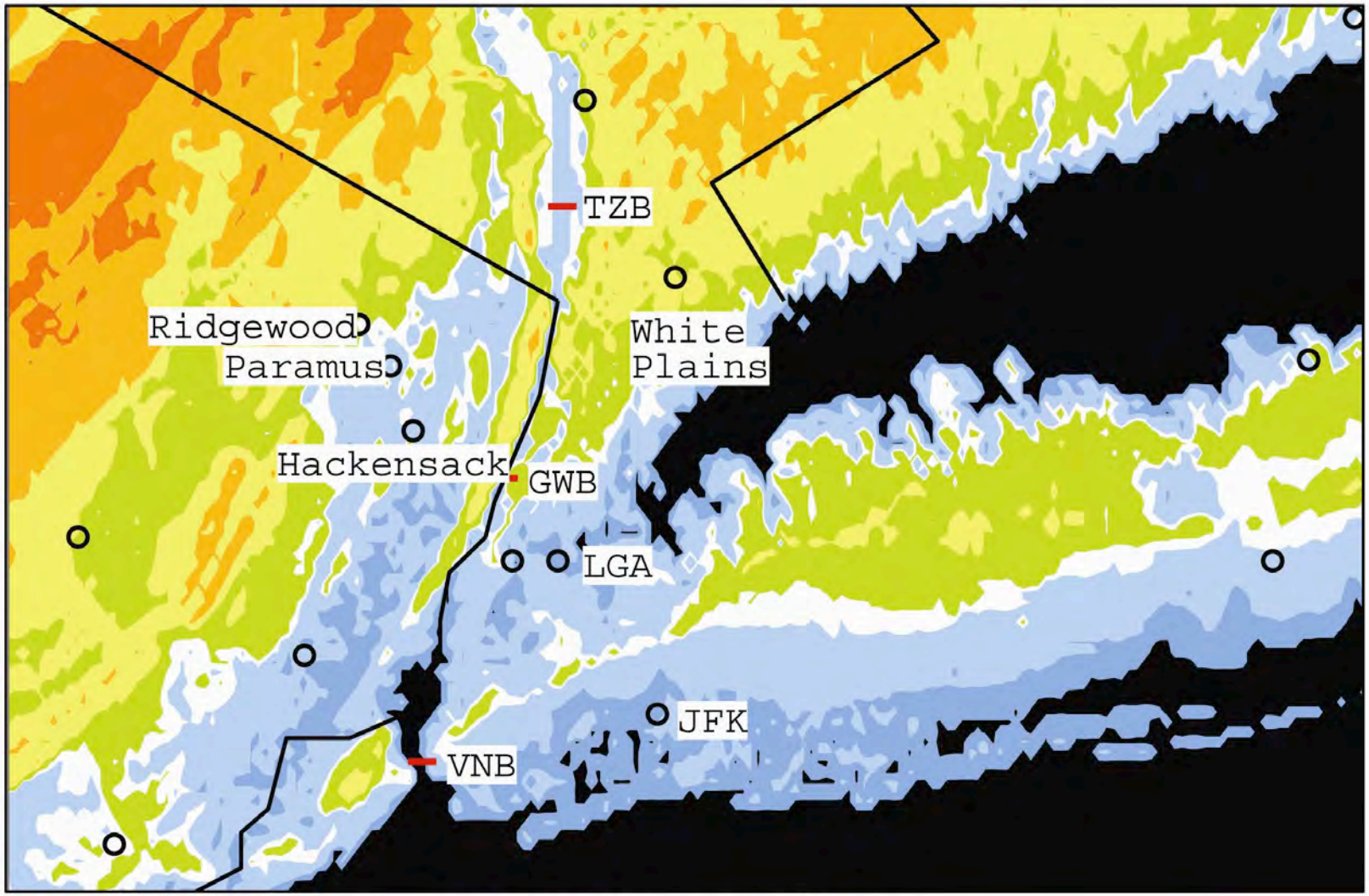
Far East: Area under Water



Population (millions) in 2000

Region (total population)	Population Under Water (for given sea level rise)			
	6m	*25 m*	*35m*	*75m*
United States (283)				
East Coast	9	41	51	70
West Coast	2	6	9	19
China + Taiwan (1275+23)	93	224	298	484
India + Sri Lanka (1009+19)	46	146	183	340
Bangladesh (137)	24	109	117	130
Indonesia + Malaysia (212+22)	23	72	85	117
Japan (127)	12	39	50	73
Western Europe (454)	26	66	88	161

Area under Water (New York Region)



Due to Sea Level Rise (m)

0 6 25 35 75 150 300 500

Paleoclimate Sea Level Data

1. **Rate of Sea Level Rise**

   - Data reveal numerous cases of rise of several m/century (e.g., MWP 1A)

2. **"Sub-orbital" Sea Level Changes**

   - Data show rapid changes ~ 10 m within interglacial & glacial periods

Ice Sheet Models Do Not Produce These

Summary: Ice Sheets

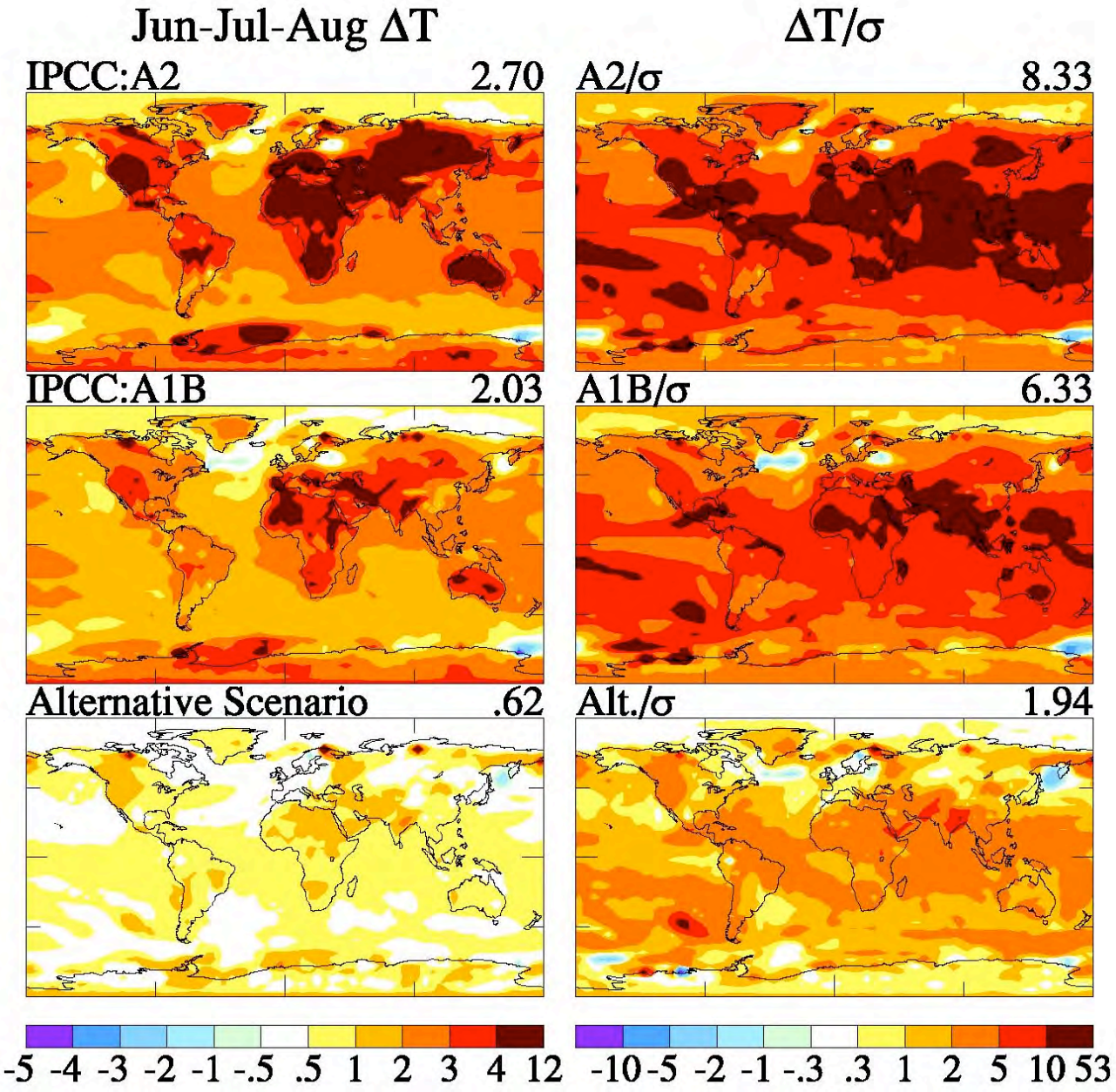
1. Human Forcing Dwarfs Paleo Forcing and Is Changing Much Faster

2. Ice Sheet Disintegration Starts Slowly but Multiple Positive Feedbacks Can Lead to Rapid Non-Linear Collapse

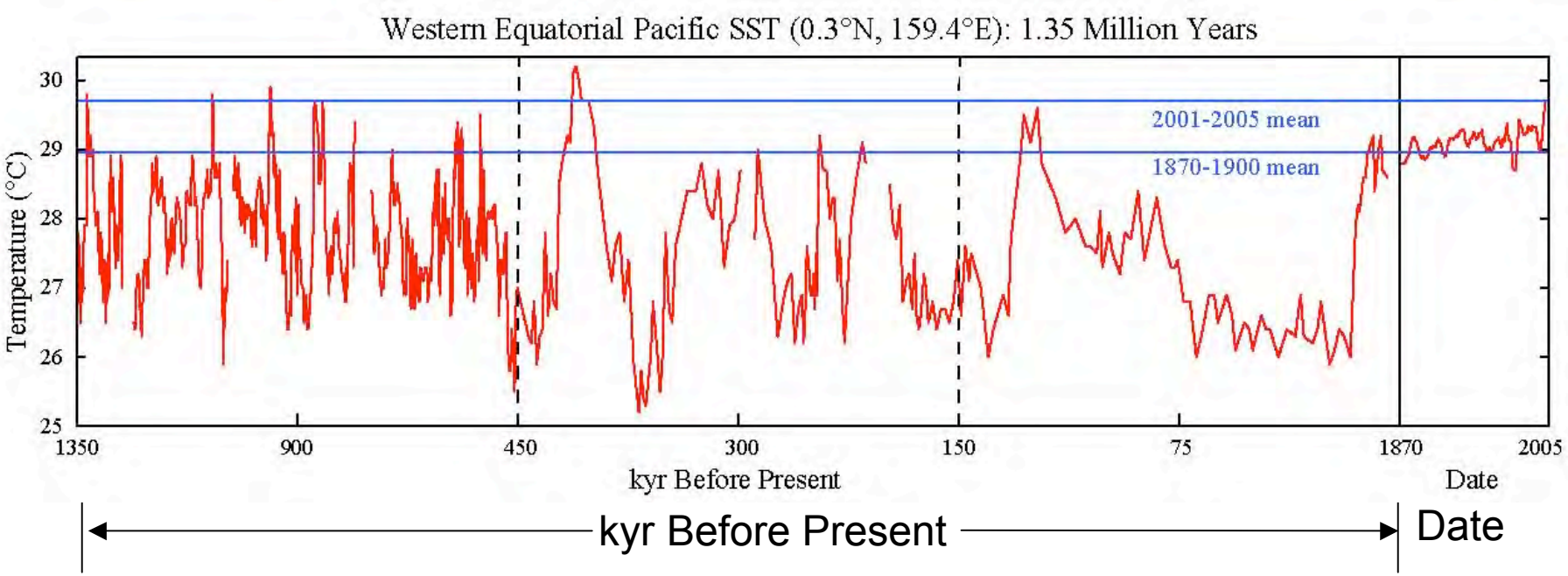
3. Equilibrium Sea Level Rise for ~3C Warming (25±10 m = 80 feet) Implies the Potential for Us to Lose Control

Simulated 2000-2100 Temperature Change

σ is interannual standard deviation of observed seasonal mean temperature for period 1900-2000.



Source: Hansen et al., *J. Geophys. Res.*, submitted.



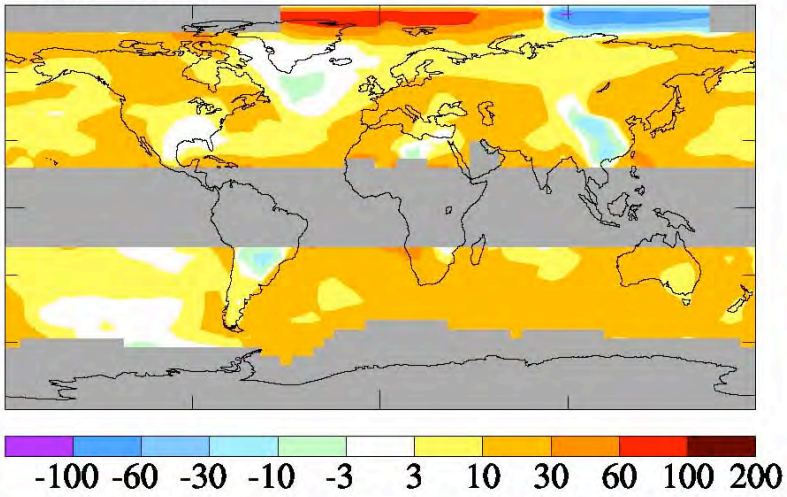
SST in Pacific Warm Pool (ODP site 806B, 0°N, 160°E) in past millennium. Time scale expanded in recent periods. Data after 1880 is 5-year mean.

Source: Medina-Elizalde and Lea, ScienceExpress, 13 October 2005;data for 1880-1981 based on Rayner et al., *JGR*, **108**, 2003, after 1981 on Reynolds and Smith, *J. Climate*, **7**, 1994.

Poleward Migration Rate of Isotherms (km/decade)

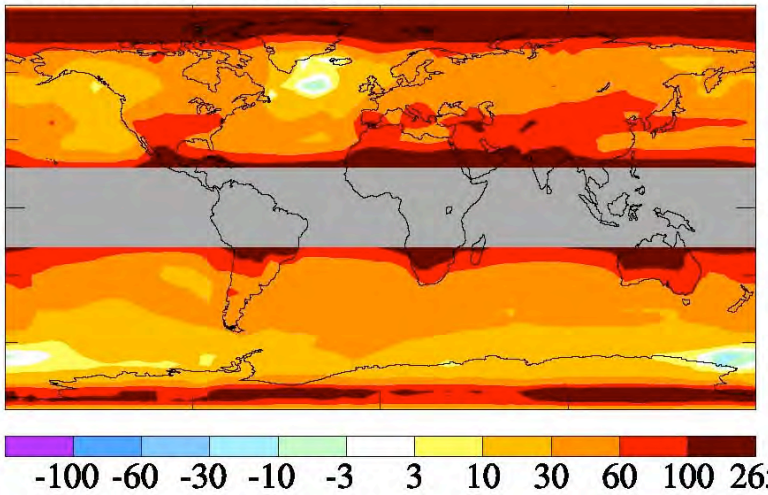
20th Century

Observations 12

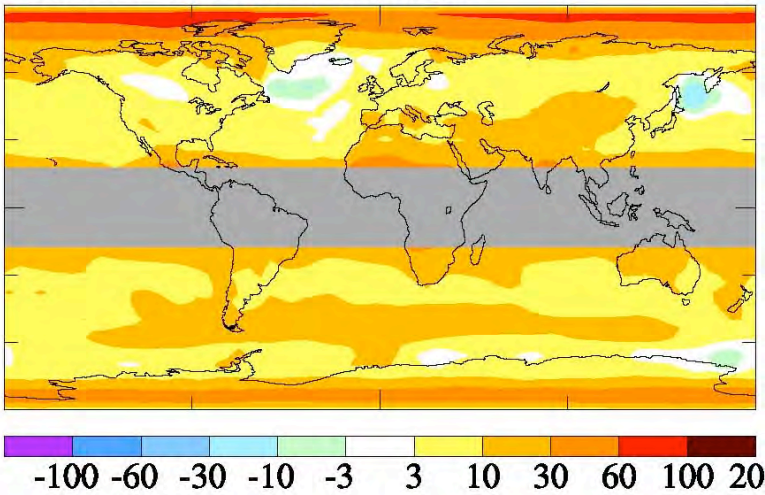


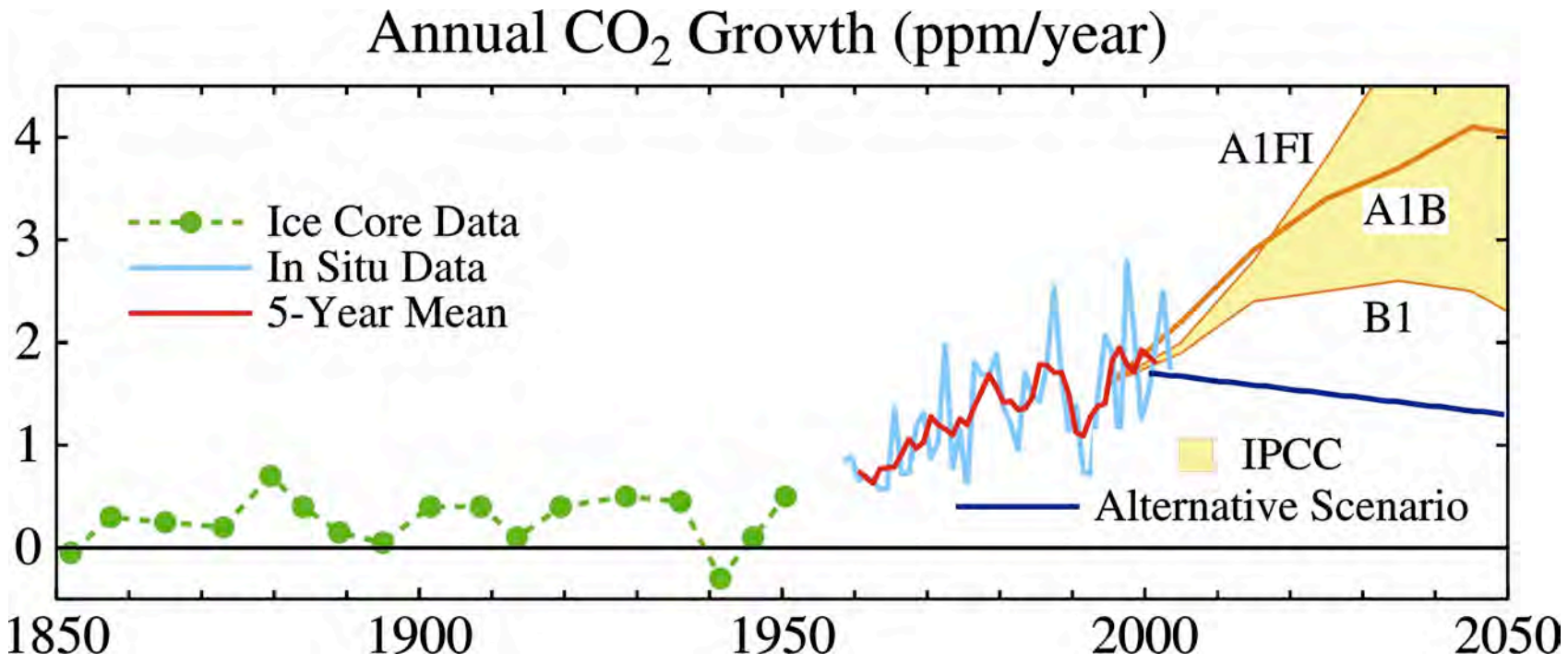
21st Century

Model: IPCC Scenario A2 59



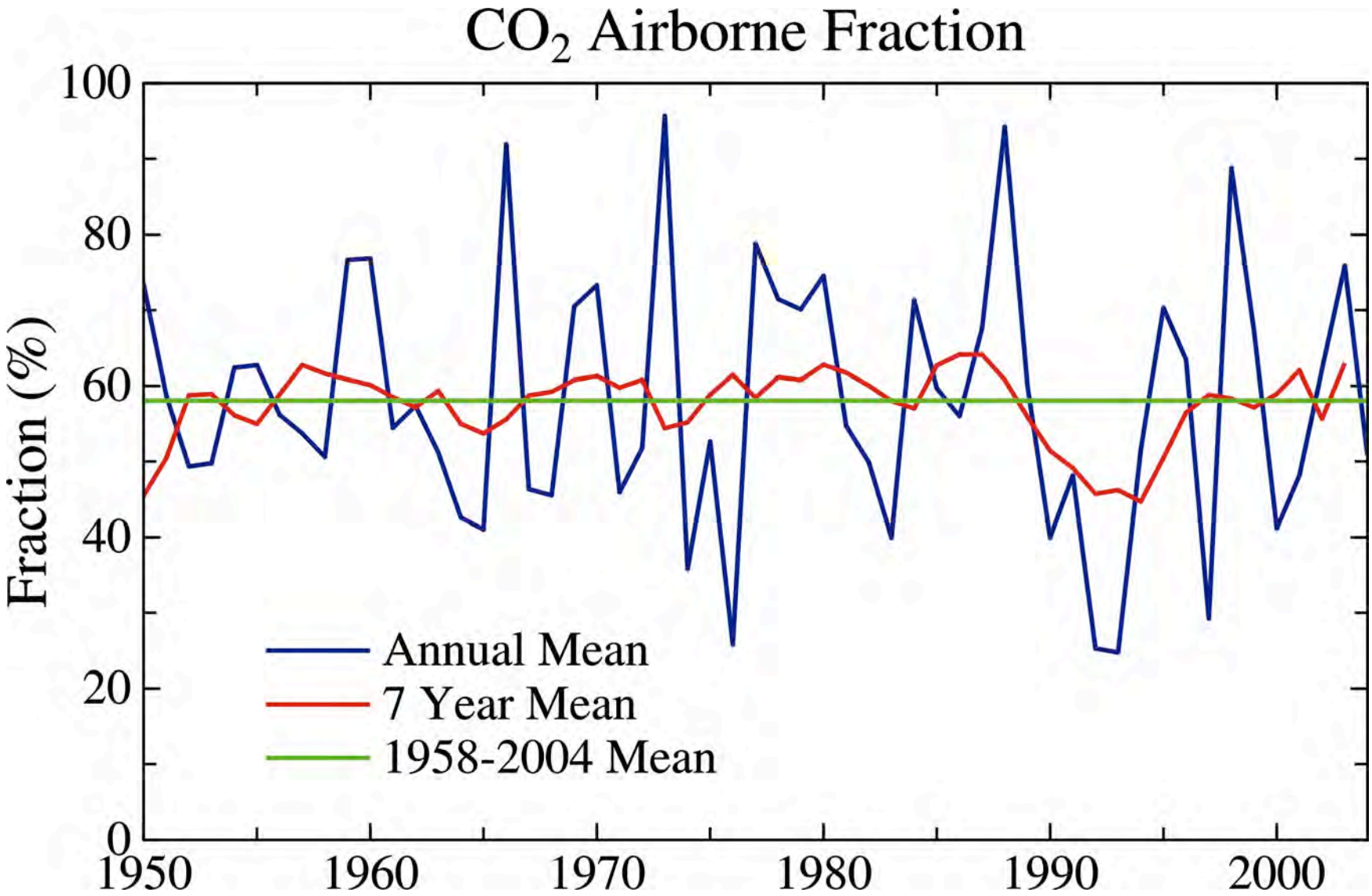
Model: Alternative Scenario 11





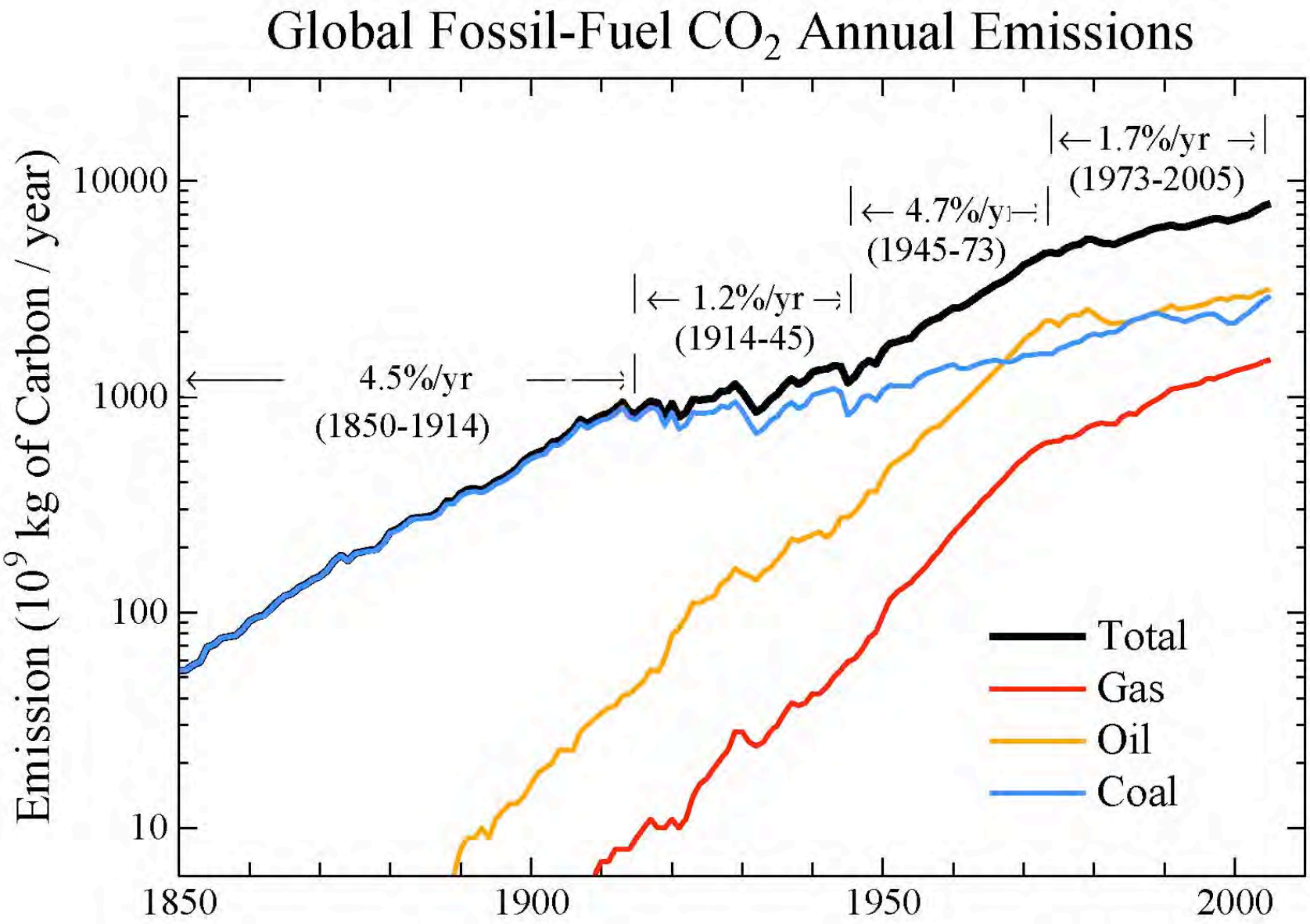
Growth rate of atmospheric CO_2 (ppm/year).

*Source: Hansen and Sato, PNAS, **101**, 16109, 2004.*

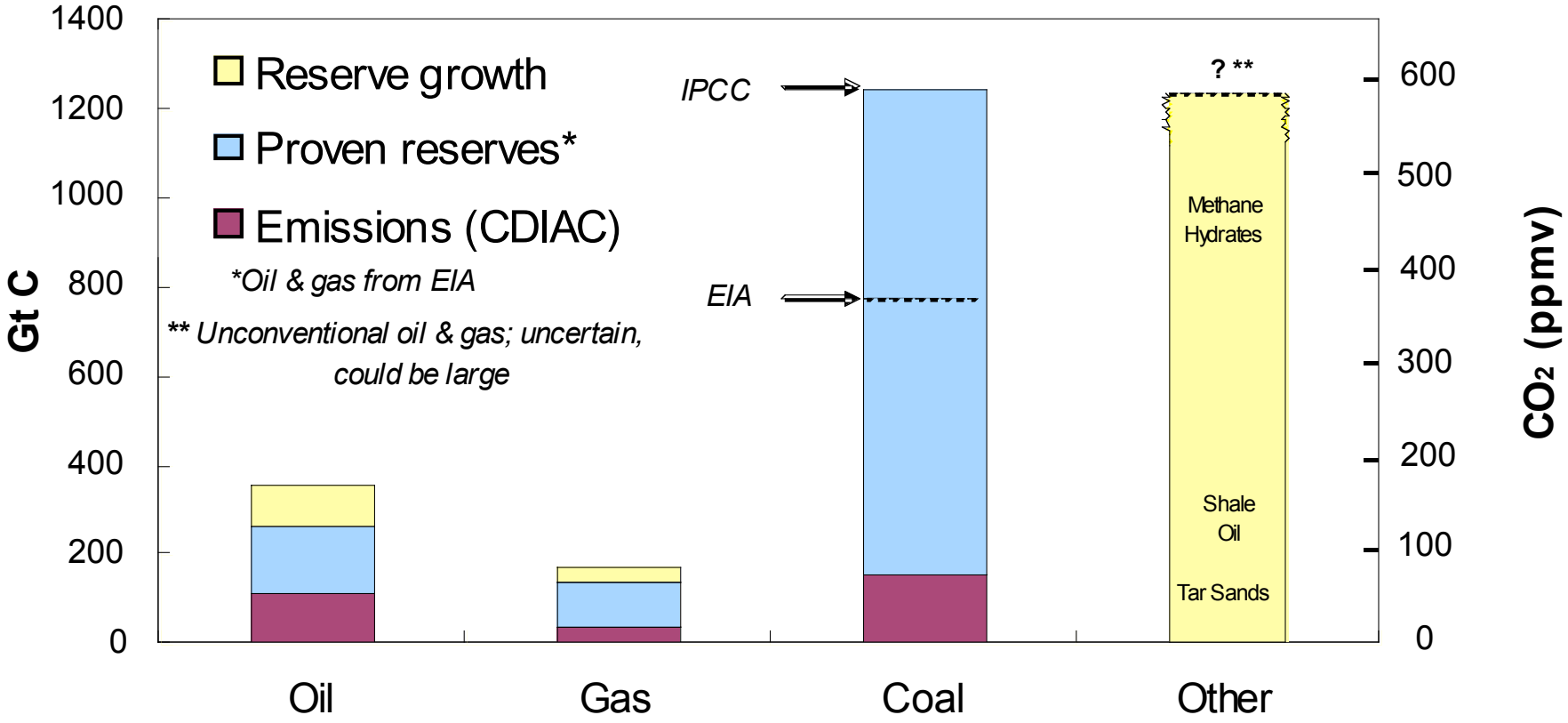


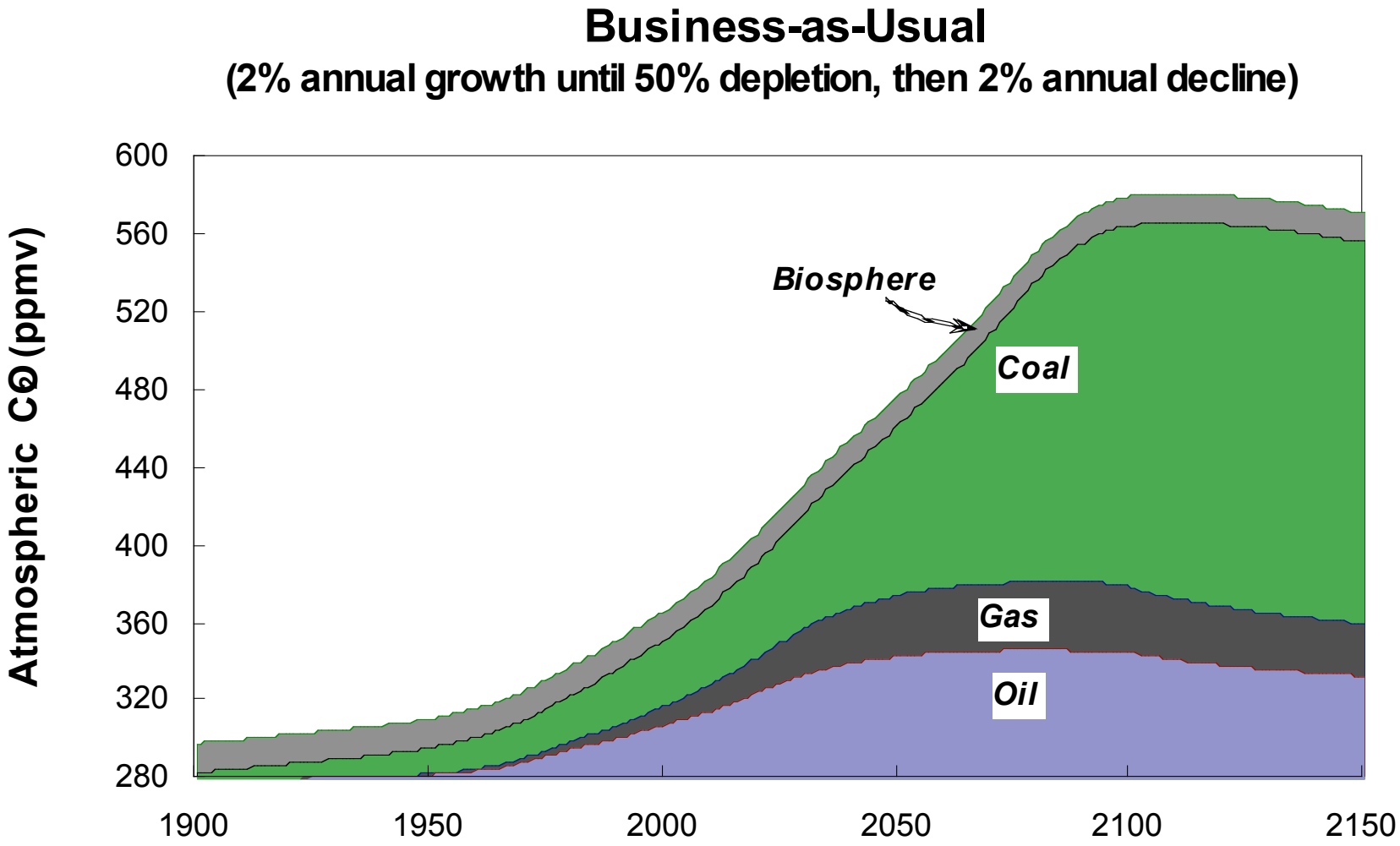
CO_2 airborne fraction, i.e., ratio of annual atmospheric CO_2 increase to annual fossil fuel CO_2 emissions.

Source: Hansen and Sato, *PNAS,* **101**, 16109, 2004.


Global Fossil-Fuel CO_2 Annual Emissions
Emission (10^9 kg of Carbon / year)
10000
1000
100
10
1850
1900
1950
2000
4.5%/yr
(1850-1914)
1.2%/yr
(1914-45)
4.7%/yr
(1945-73)
1.7%/yr
(1973-2005)
Total
Gas
Oil
Coal

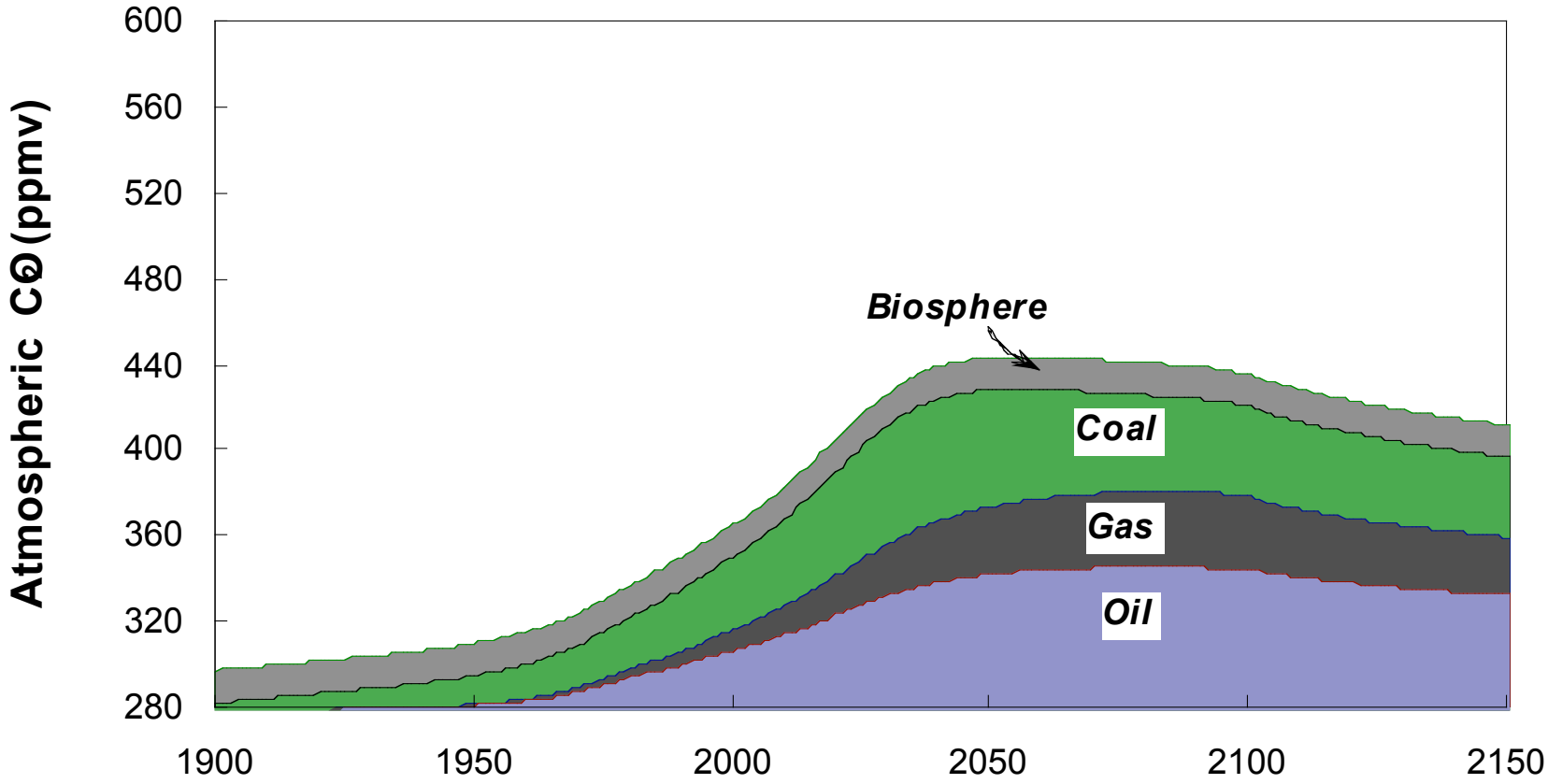
Fossil Fuel Reservoirs and 1750–2004 Emissions




Business-as-Usual
(2% annual growth until 50% depletion, then 2% annual decline)
Atmospheric CO2 (ppmv)
600
560
520
480
440
400
360
320
280
1900
1950
2000
2050
2100
2150
Biosphere
Coal
Gas
Oil

Alternative Case: Coal Phaseout

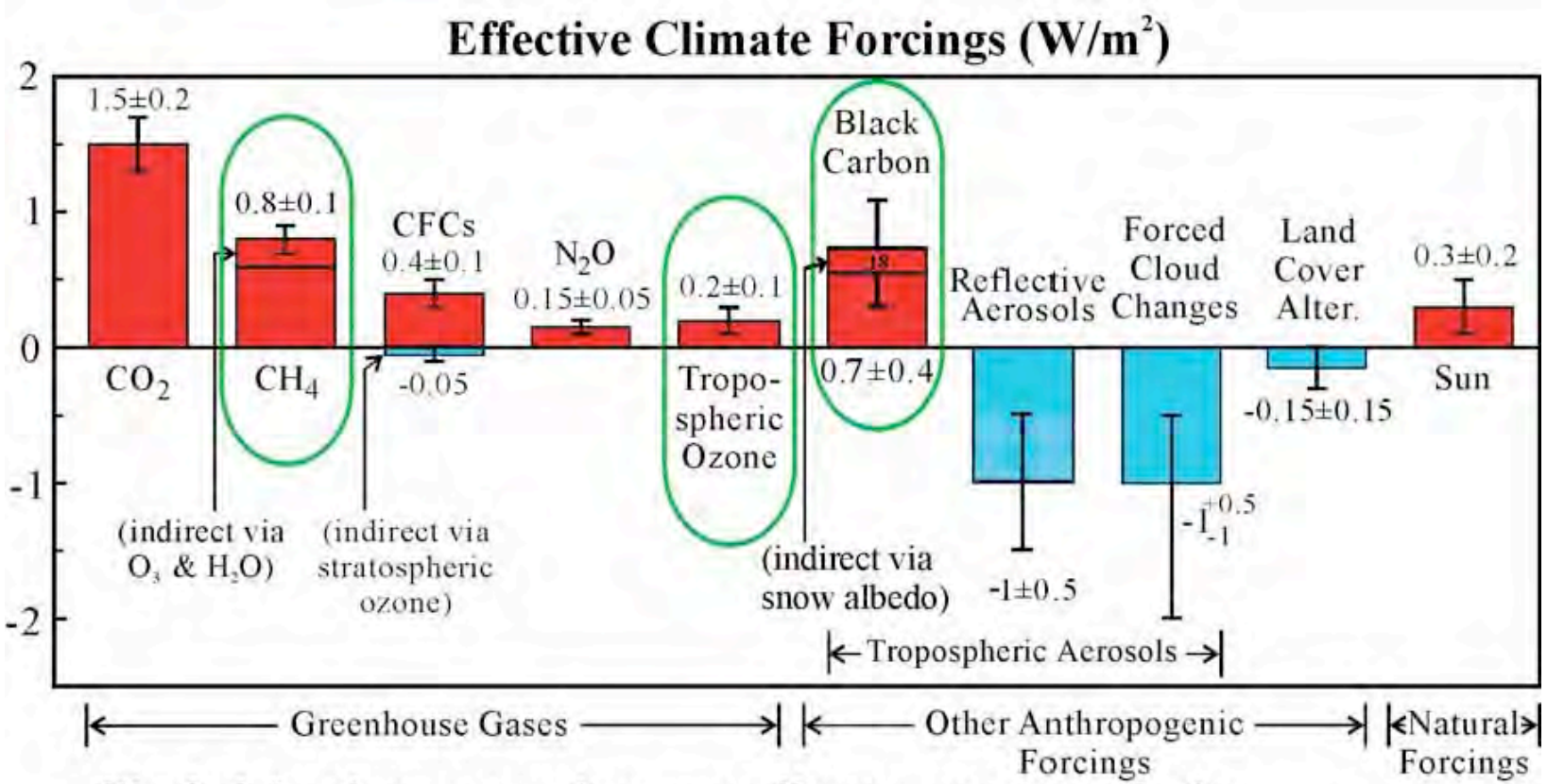
(+2%/yr to 2012; +1%/yr to 2022; linear shutdown between 2025-2050)



Is Alternative Scenario Feasible?

Example: Phase-Out of 'Dirty' Coal

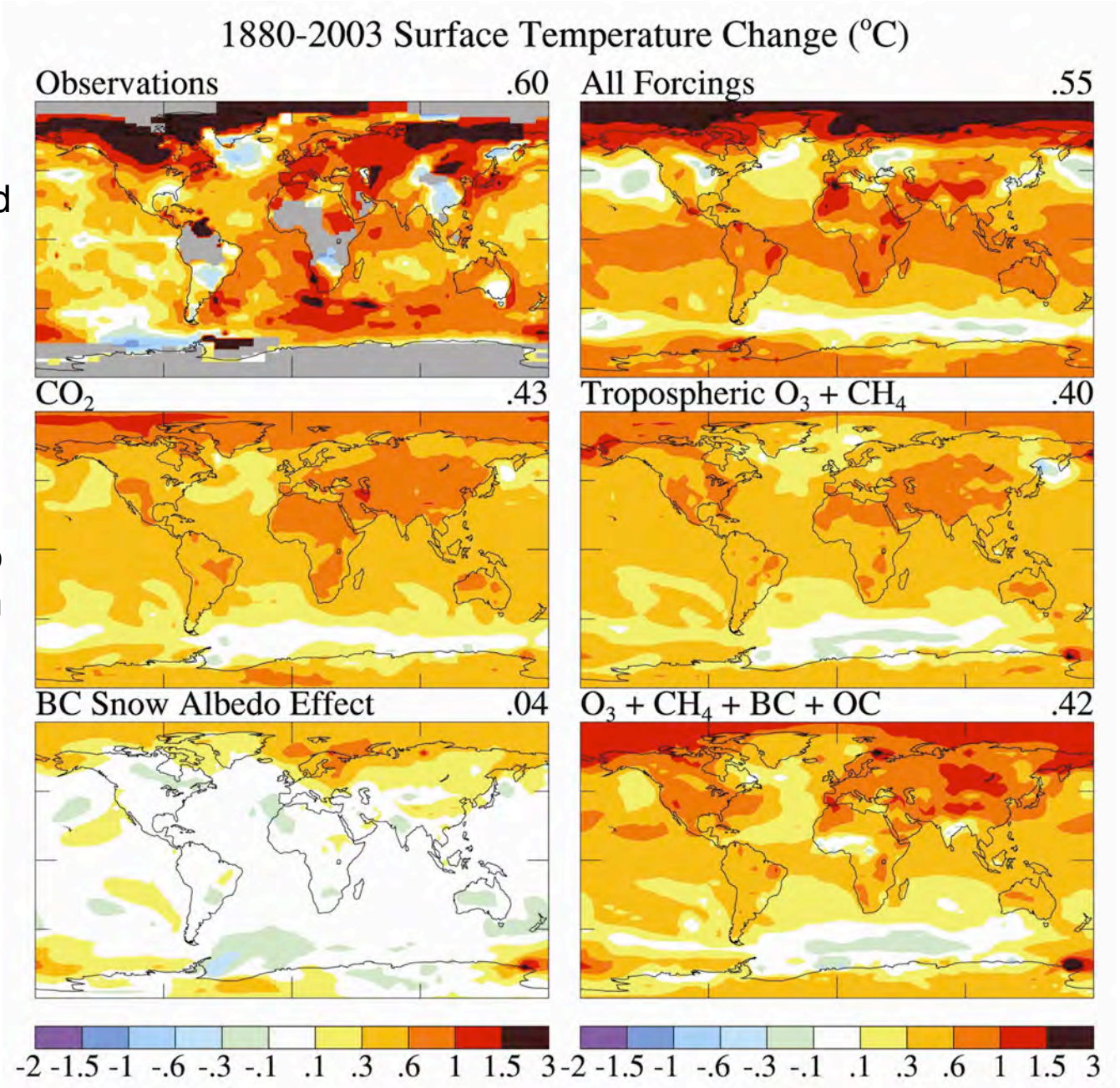
- CO_2 Sequestered at New Coal Power Plants after 2012/2022 in Developed/Developing Countries
- Coal Power Plants w/o Sequestration Bull-Dozed During 2025-2050 (Decision required by ~2020)
- Slowly Increase Carbon Tax, Stretch Conventional Oil/Gas, Avoiding Use of Non-Conventional Fossil Fuels, Permitting Time to Develop non-CO_2 Technologies
- Non-CO_2 Climate Forcings Reduced Via Clean Development Incentives



Circled forcings are prime contributors to air pollution.

Temperature change observed and simulated for different forcing mechanisms.

Aerosol forcing (negative) is thought to be slightly excessive in in the 'all forcing' simulation.



Source: Hansen et al., *J. Geophys. Res.*, submitted.

Workshop at East-West Center, Honolulu

April 4-6, 2005; Local Host: Intn'l. Center for Climate & Society, Univ. Hawaii

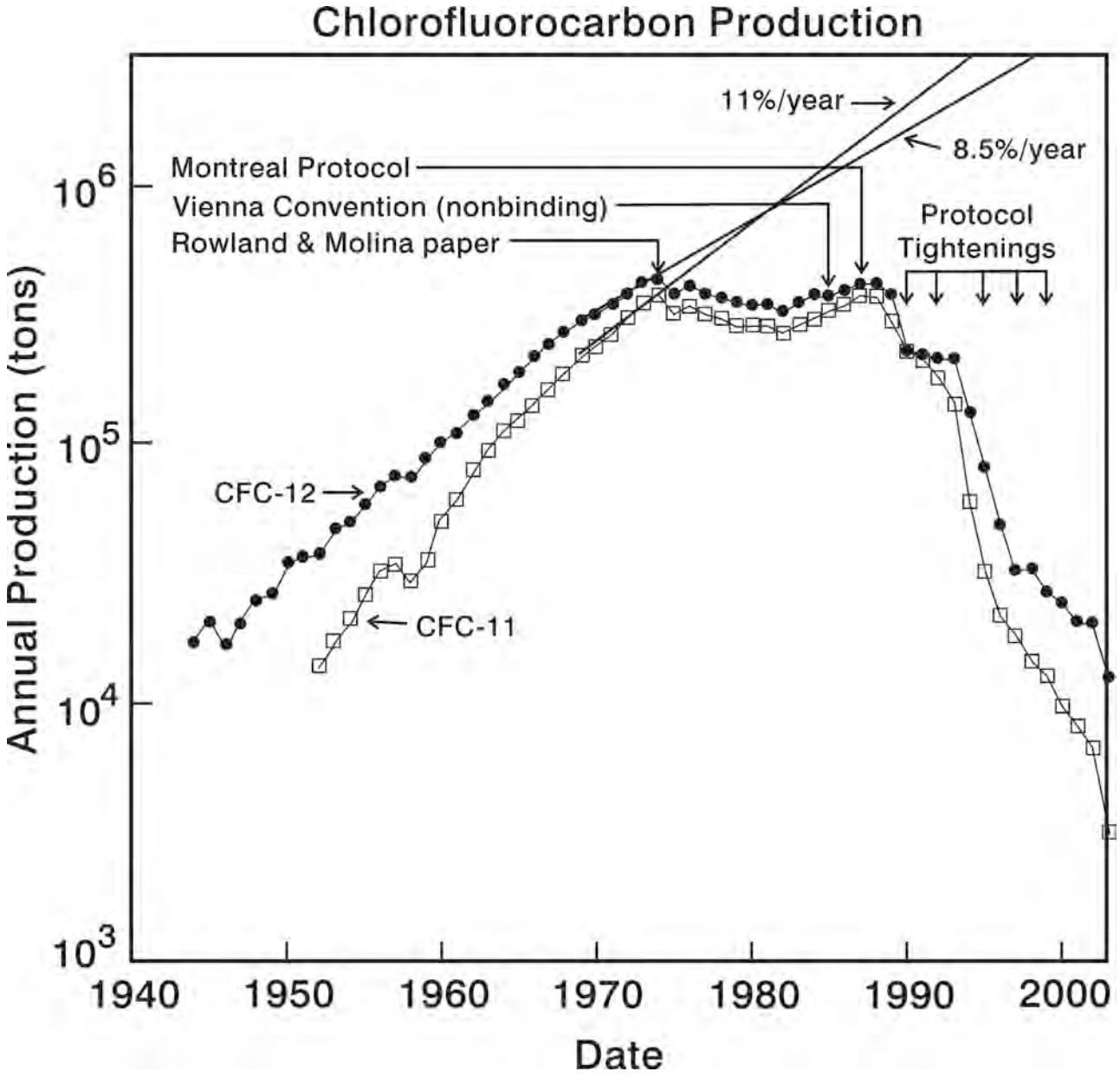
"Air Pollution as Climate Forcing: A Second Workshop"

- **Multiple Benefits by Controlling CH_4 and CO**
  (benefits climate, human health, agriculture)
- **Multiple Benefits from Near-Term Efficiency Emphasis**
  (climate & health benefits, avoid undesirable infrastructure)
- **Targeted Soot Reduction to Minimize Warming from Planned Reductions of Reflective Aerosols**
  (improved diesel controls, biofuels, small scale coal use)
- **Targeted Improvements in Household Solid Fuel Use**
  (reduces CH_4, CO, BC; benefits climate, human health, agriculture)

Conclusion: Technical Cooperation Offers Large Mutual Benefits to Developed & Developing Nations.

References:

- **Air Pollution as Climate Forcing: 2002 Workshop; 2005 Workshop** http://www.giss.nasa.gov/meetings/pollution02/ and 2005/


Chlorofluorocarbon Production
11%/year
8.5%/year
Montreal Protocol
Vienna Convention (nonbinding)
Rowland & Molina paper
Protocol
Tightenings
CFC-12
CFC-11
Annual Production (tons)
10^6
10^5
10^4
10^3
1940
1950
1960
1970
1980
1990
2000
Date

Ozone Success Story

1. **Scientists** : Clear warning

2. **Media** : Transmitted the message well

3. **Special Interests** : Initial skepticism, but forsook disinformation, pursued advanced technologies

4. **Public** : quick response; spray cans replaced; no additional CFC infrastructure built

5. **Government** : U.S./Europe leadership; allow delay & technical assistance for developing countries

Global Warming Story

1. **Scientists** : Fail to make clear distinction between climate change & BAU = A Different Planet

2. **Media** : False "balance", and leap to hopelessness

3. **Special Interests** : Disinformation campaigns, emphasis on short -term pr ofits

4. **Public** : understandably confused, un interested

5. **Government** : Seems affected by special interests; fails to lead – no Winston Churchill today

As it appears that the world may pass a tipping point soon, beyond which it will be impossible to avert massive future impacts on humans and other life on the planet:

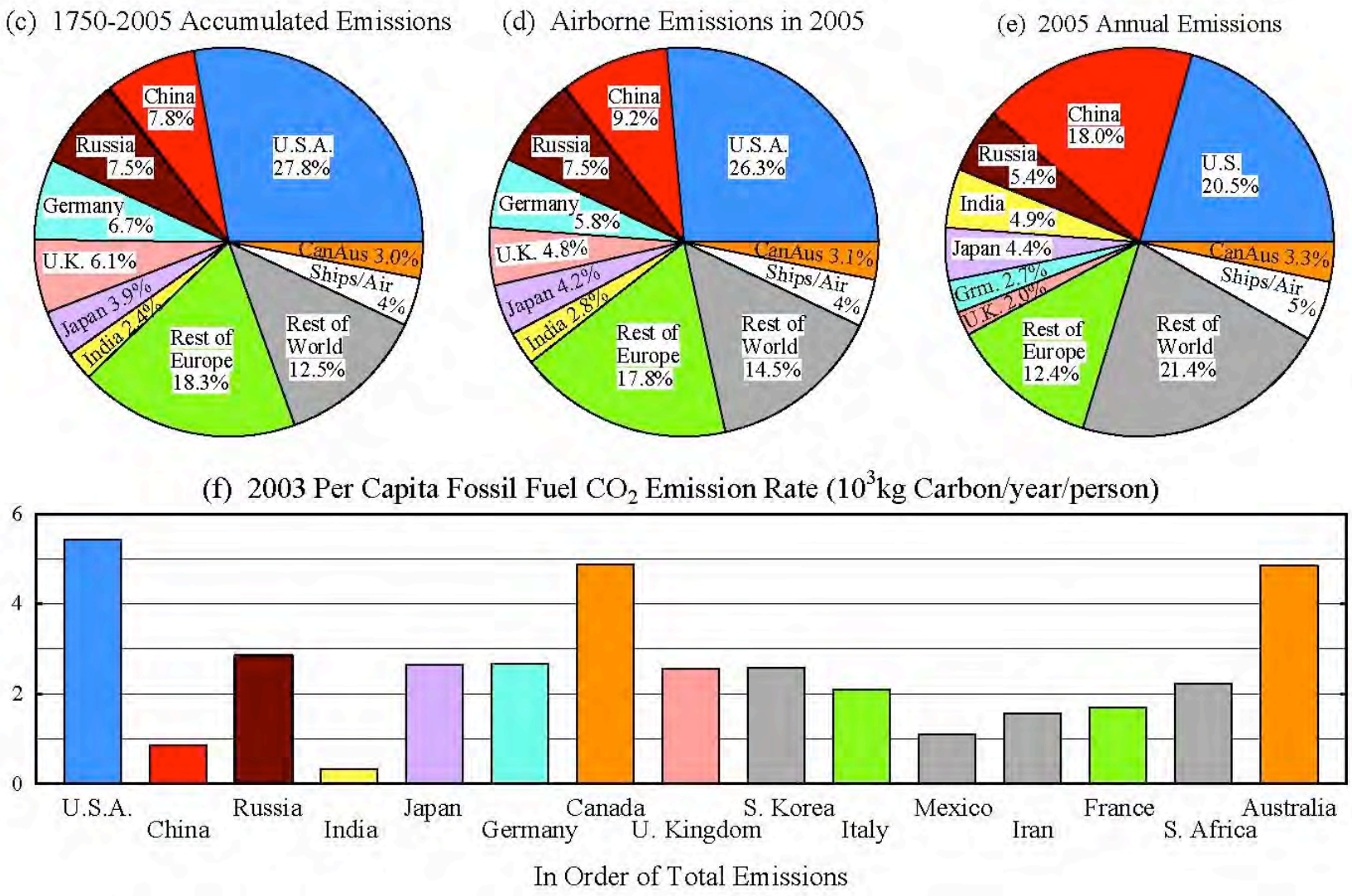
Who Bears (Legal/Moral) Responsibility?

1. Scientists?
2. Media?
3. Special Interests?
4. U.S. Politicians?

5a. Today's U.S. Public?

5b. U.S. Children/Grandchildren?

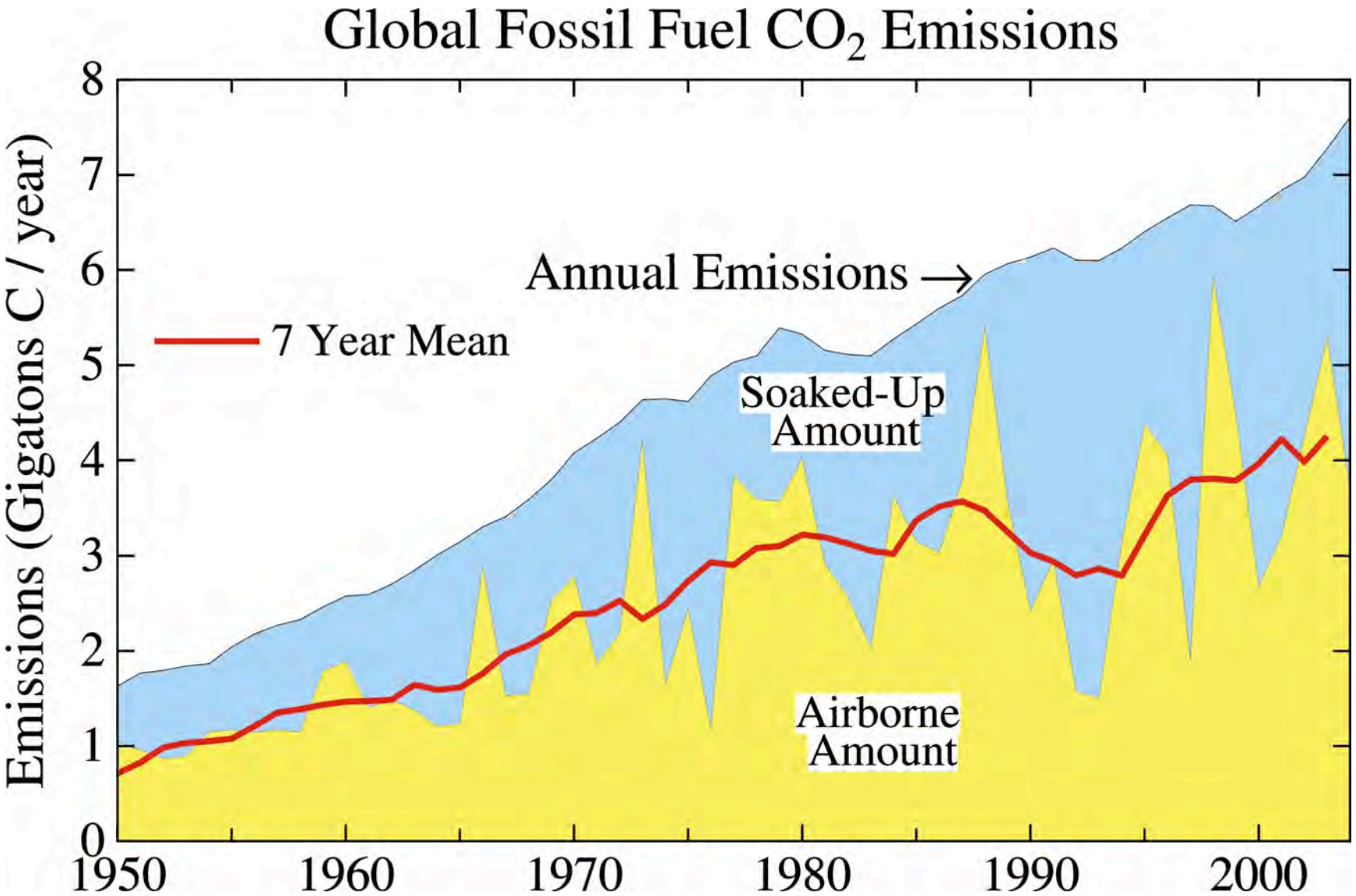
Who Will Pay?


(c) 1750-2005 Accumulated Emissions
China 7.8%
U.S.A. 27.8%
Russia 7.5%
Germany 6.7%
U.K. 6.1%
CanAus 3.0%
Ships/Air 4%
Japan 3.9%
India 2.4%
Rest of Europe 18.3%
Rest of World 12.5%
(d) Airborne Emissions in 2005
China 9.2%
U.S.A. 26.3%
Russia 7.5%
Germany 5.8%
U.K. 4.8%
CanAus 3.1%
Ships/Air 4%
Japan 4.2%
India 2.8%
Rest of Europe 17.8%
Rest of World 14.5%
(e) 2005 Annual Emissions
China 18.0%
U.S. 20.5%
Russia 5.4%
India 4.9%
Japan 4.4%
CanAus 3.3%
Grm. 2.7%
Ships/Air 5%
U.K. 2.0%
Rest of Europe 12.4%
Rest of World 21.4%
(f) 2003 Per Capita Fossil Fuel CO_2 Emission Rate (10^3kg Carbon/year/person)
6
4
2
0
U.S.A.
China
Russia
India
Japan
Germany
Canada
U. Kingdom
S. Korea
Italy
Mexico
Iran
France
S. Africa
Australia
In Order of Total Emissions

Summary: Is There Still Time?

Yes, But:

- Alternative Scenario is Feasible, But It Is Not Being Pursued
- Action needed now; a decade of BAU eliminates Alter. Scen.
- Best Hope: Public Must Become Informed and Get Angry

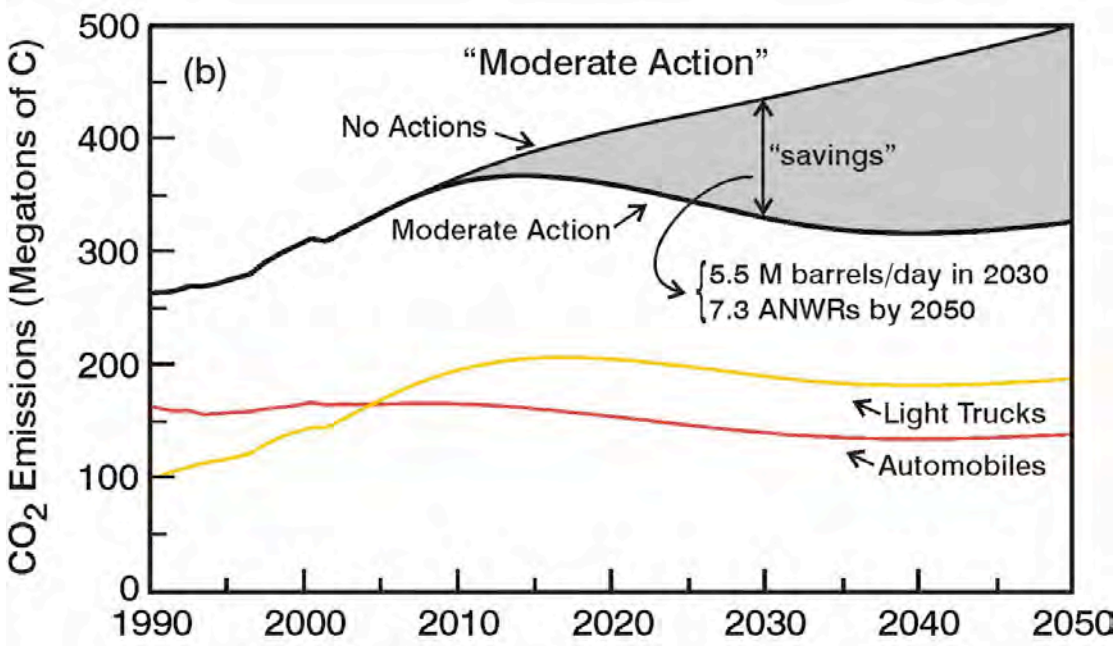


Global fossil fuel CO_2 emissions with division into portions that remain airborne or are soaked up by the ocean and land.

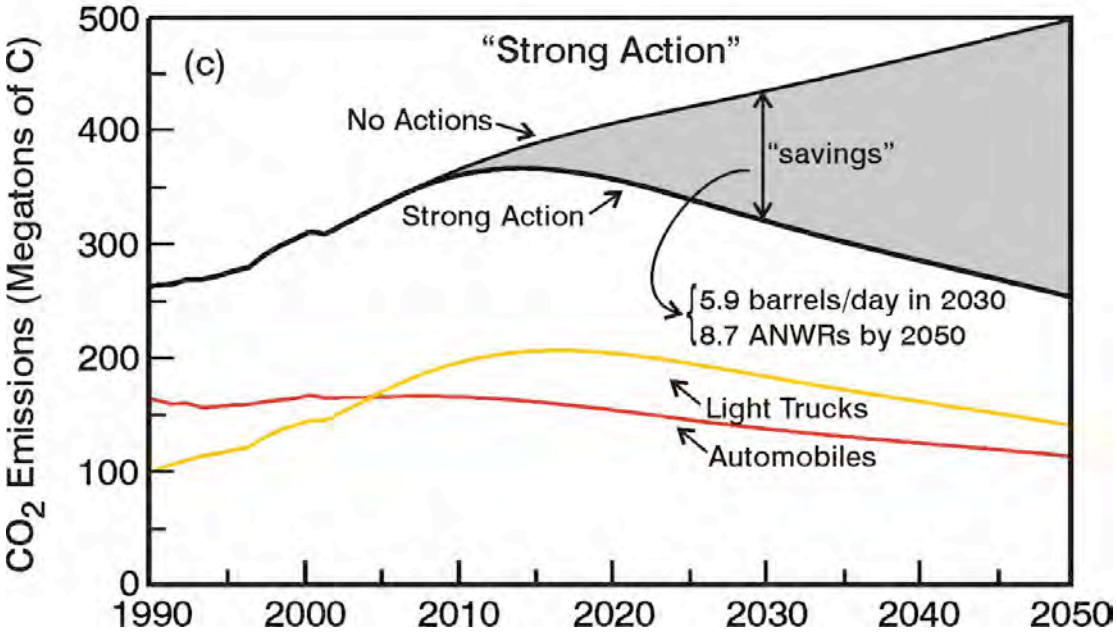
Source: Hansen and Sato, *PNAS,* **101**, 16109, 2004.

U.S. Auto & Light Truck CO_2 Emissions

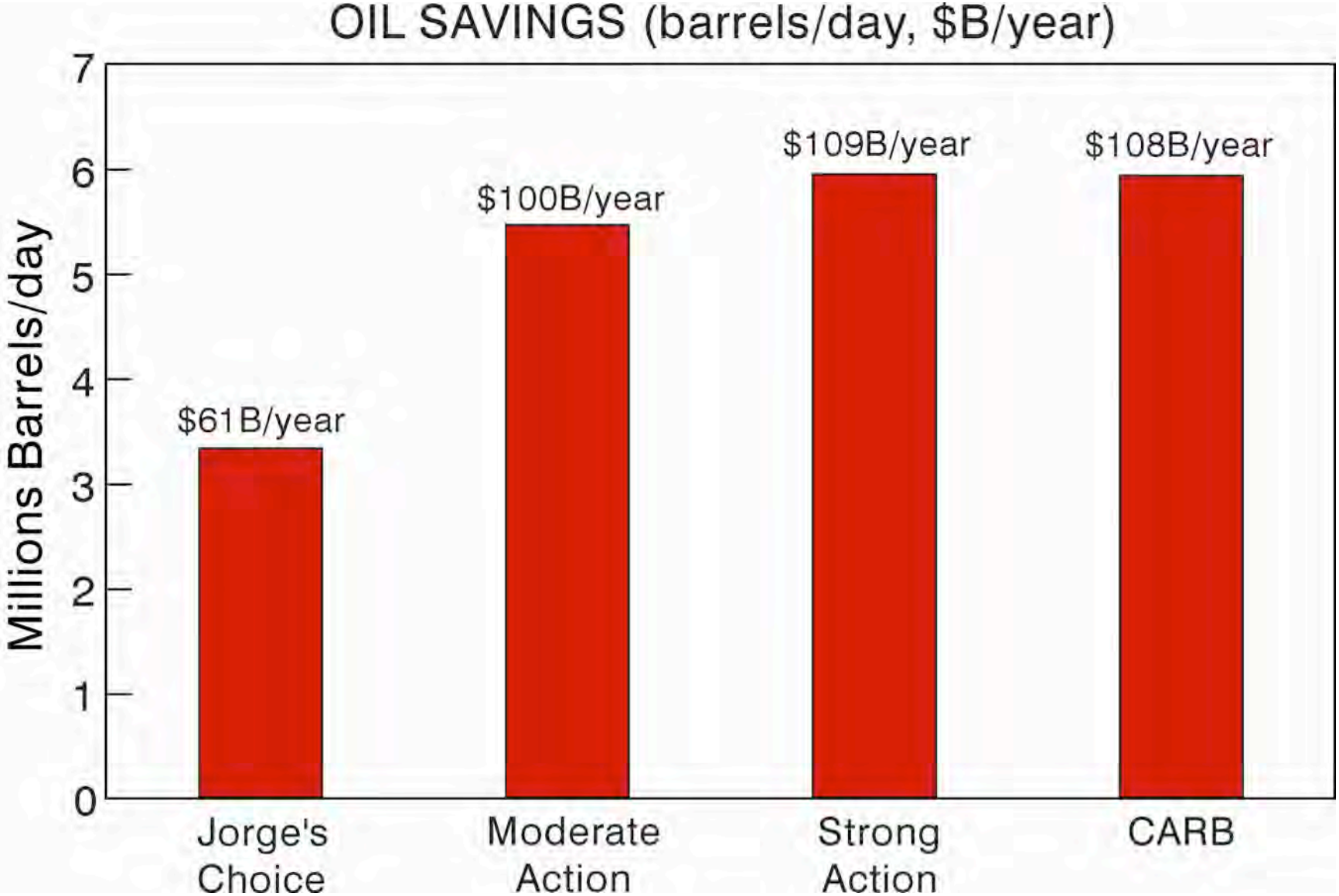
"Moderate Action" is NRC "Path 1.5" by 2015 and "Path 2.5" by 2030.



"Strong Action" adds hydrogen-powered vehicles in 2030 (30% of 2050 fleet).
Hydrogen produced from non-CO_2 sources only.



Source: On the Road to Climate Stability, Hansen, J., D. Cain and R. Schmunk., *to be submitted*.



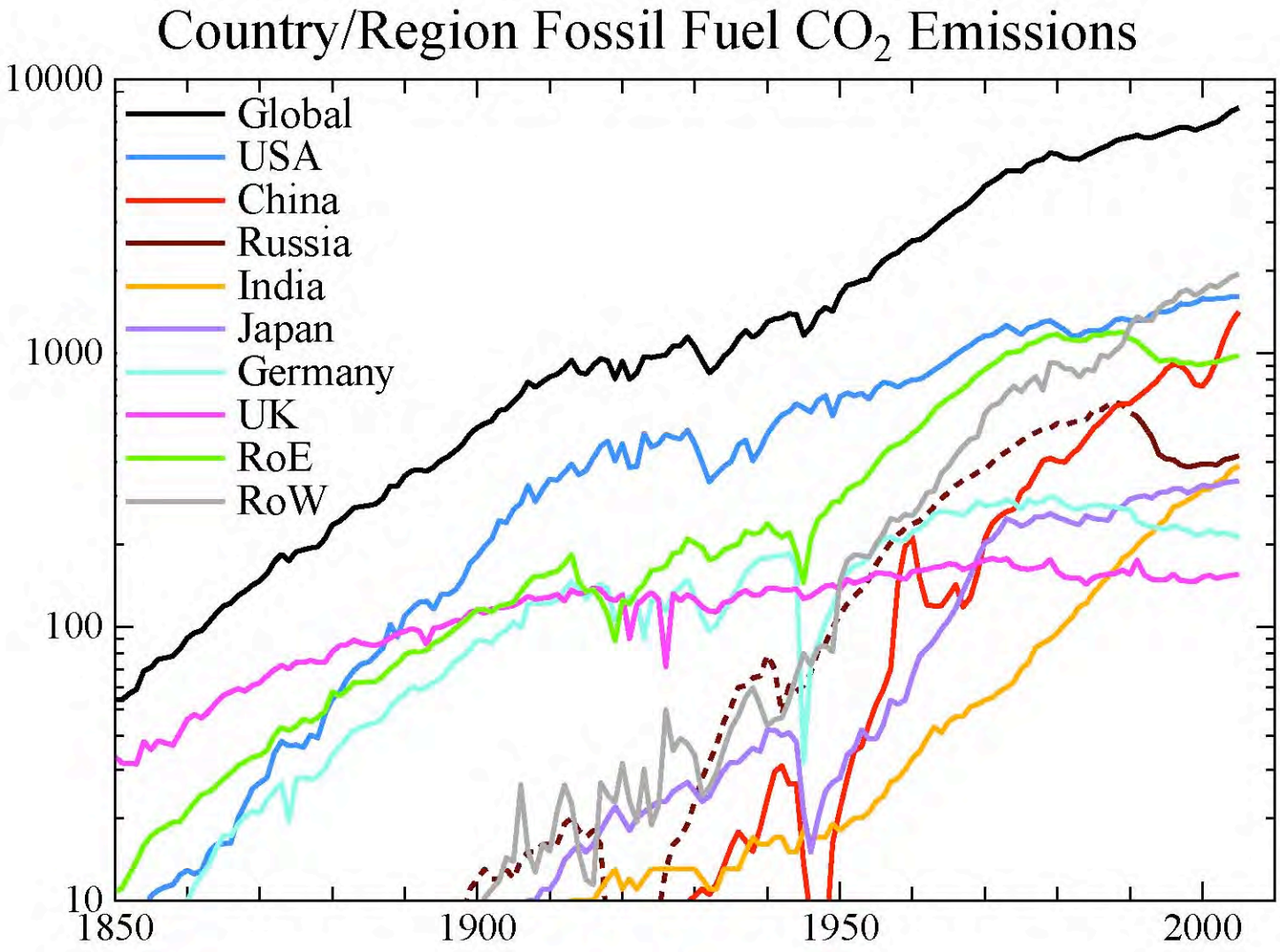
United States annual savings (at $50/barrel, today's dollars) in 2030 for alternative automotive efficiency improvements.

Source: On the Road to Climate Stability, Hansen, J., D. Cain and R. Schmunk., to be submitted.

Public Needs to Know Facts of Life

- CO_2 < 450ppm or 'Different Planet'
- ~ ¼ of Emissions are 'Forever'
- Gradual Carbon 'Tax' is Essential
- Except Oil/Gas, Must Sequester C
- Must → Renewables Eventually

What's So Bad About Clean Air?


Country/Region Fossil Fuel CO_2 Emissions
10000
1000
100
10
1850
1900
1950
2000
Global
USA
China
Russia
India
Japan
Germany
UK
RoE
RoW

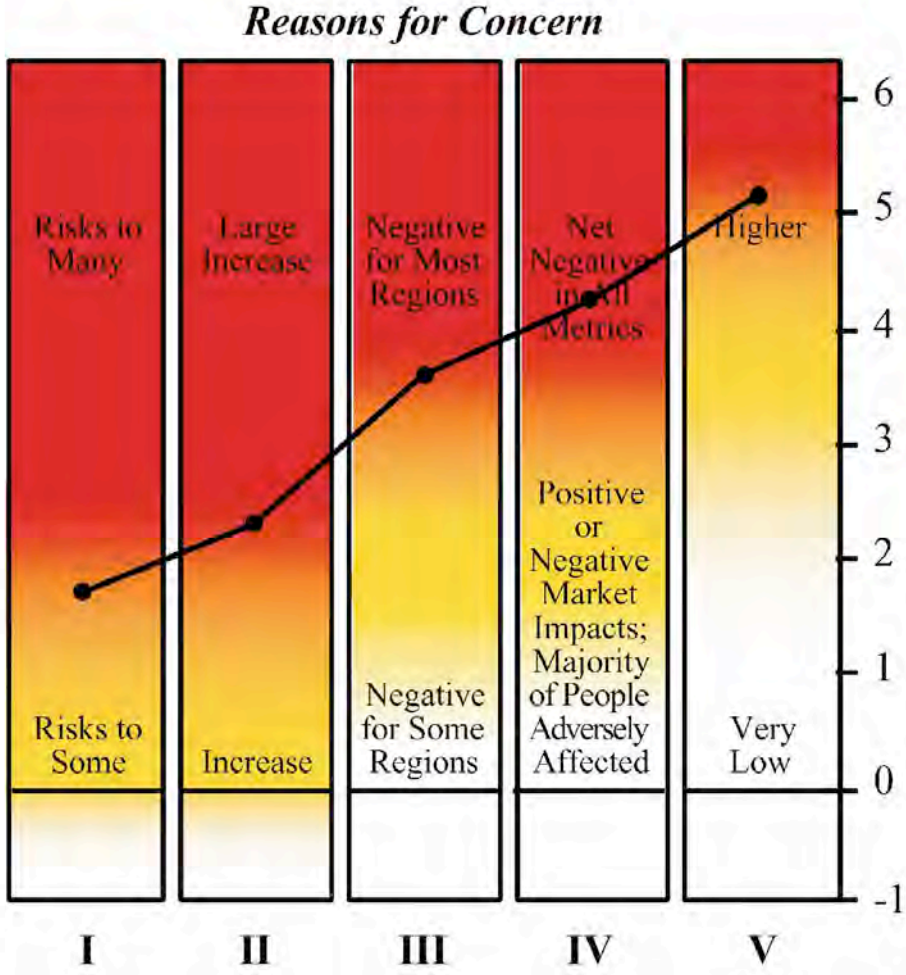
IPCC Burning Embers

White: neutral or small positive or negative impacts

Yellow: negative impacts for some systems or low risks

Red: negative impacts or risks that are more widespread and/or greater in magnitude

I	Risks to Unique and Threatened Systems
II	Risks from Extreme Climate Events
III	Distribution of Impacts
IV	Aggregate Impacts
V	Risks from Future Large-Scale Discontinuities



Reasons for concern about projected climate change impacts

Source: IPCC *Climate Change 2001;* S. Schneider & M. Mastrandrea, *PNAS,* **102**, 15728, 2005.